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Analysis of Digital Topographic Data Issues in Support of Synthetic Environment Terrain Data Base Generation

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this study is to analyze digital topographic data (DTD) problems and issues involved in the process of synthetic environment terrain data base generation systems (DBGS). The first phase of the study examined four systems: (1) U.S. Army TEC, Digital Products Center, DBGS supported by LNK, Alexandria, VA; (2) Close Combat Tactical Trainer terrain DBGS, operated by Evans and Sutherland, Salt Lake City, UT; (3) USAF 58th Training Support Squadron's Mission Training Support System terrain DBGS operated by Lockheed Martin, Kirkland AFB, NM; (4) USAF Special Operations Command's Special Operations Forces Aircrew Training System terrain DBGS operated by Loral Defense Systems, Hurlburt Field, FL. All of these systems use National Imagery & Mapping Agency DTD and produce run time data bases for various types of image generators supporting different polygonal representations. The second phase of the report identifies the problems associated with the use of current DTD products as inputs to the SE DBGS process. This report is to be used as an educational tool for understanding the issues and problems of these four systems regarding the generation of SE terrain data bases from DTD and alternate sources. The results of this study identified several key issues and (Continued on reverse)

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problems with SE terrain data base generation. The recommendations and conclusions are based on observations of these four systems. The impetus of this report is to create a dialogue with the M&S community and the producers of DTD and SE terrain data bases, both Government and private industry, to establish a means to resolve the most significant problems identified in the study.

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LIST OF ACRONYMS/ABBREVIATIONS

The following acronyms/abbreviations are used in this report:

ADRG - ARC Digitized Raster Graphics
AFB - Air Force Base
AGSS - Aerial Gunner and Scanner Simulator
AML - ARC Macro Language
AMSAA - Army Material Systems Analysis Activity
BMC - Bottom Materials Composition
C3I - Command, Control, Communications and Intelligence
CAD - Computer-Aided Design
CCTT - Close Combat Tactical Trainer
CD-ROM - Compact Disk-Read Only Memory
CGF - Computer Generated Forces
CIB - Controlled Image Base
CM - Configuration Management
CMU - Carnegie Mellon University
CTDB - Compact Terrain Data Base
DBGS - Data Base Generation System
DCW - Digital Chart of the World
DEM - Digital Elevation Model
DET - Data Extraction Tool
DFAD - Digital Feature Analysis Data
DIGEST - Digital Geographic Information Exchange Standard
DIS - Distributed Interactive Simulation
DLG - Digital Line Graph
DMZ - Demilitarized Zone
DoD - Department of Defense
DPC - Digital Products Center
DPPDB - Digital Point Positioning Data Base
DPS - Digital Production System
DSPW - Digital Stereo Photogrammetric Workstation
DTD - Digital Topographic Data
DTED - Digital Terrain Elevation Data
DTOP - Digital Topographic Data
DTP - Decorated Terrain Processor
E&S - Evans & Sutherland
E2DIS - Environmental Effects in Distributed Interactive Simulation
ELT - Electronic Light Table
ESid - Evans & Sutherland Identifier
ESIG - Evans & Sutherland Image Generator
ESRI - Environmental Systems Research Institute
FAC - Feature & Analysis Code
FACC - Feature and Attribute Coding Catalog

FACS - Feature and Attribute Coding System
FID - Feature Identification
FLIR - Forward Looking Infrared
FY - Fiscal Year
GIS - Geographic Information System
HMMWV - High Mobility Multipurpose Wheeled Vehicle
ICTDB - Integrated CGF Terrain Data Base
IDEFO - Integrated Definition for Function Modeling
IG - Image Generator
IR - Infrared
ITD - Interim Terrain Data
JOG - Joint Operations Graphic
JOG-A - Joint Operations Graphic-Air
LEOW - Low-Cost Exploitation Operations Workstation
LULC - Land Use Land Cover
MB - Megabyte
MC&G - Mapping, Charting and Geodesy
MCC - Material Composition Category
MCS - Material Composition Secondary
MCU - Material Composition Underlying
MEDS - Minimum Essential Data Set
MOBA - Military Operations in Built-Up Areas
ModSAF - Modular Semi-Automated Forces
MPO - Multi-Purpose Operation
MRS - Mission Rehearsal System
MTSS - Mission Training Support System
NHAP - National High Altitude Photography
NIST - National Institute for Standards and Technology
NITF - National Imagery Transmission Format
nmi - Nautical Miles
NRMM II - NATO Reference Mobility Model II
NVG - Night Vision Goggles
OFT - Operational Flight Trainer
ONC - Operational Navigation Chart
OTW - Out-the-Window
PVD - Plan View Display
QA - Quality Assurance
RPF - Raster Product Format
RSF - Radar Significance Factor
RST - Road Surface Type
SAF - Semi-Automated Forces
SAKI - Saudi Arabia, Kuwait & Iraq
SAR - Search and Rescue

LIST OF ACRONYMS/ABBREVIATIONS - Continued

SDBF - Simulator Data Base Facility
SGI - Silicon Graphics Incorporated
SIF - Standard Simulator Data Base (SSDB) Interchange Format
SimMaps - Simulation Maps
SIMNET - Simulator Network
SMC - Surface Material Category
SOF ATS - Special Operations Forces Aircrew Training System
SOF - Special Operations Forces
SOFPREP - Special Operations Forces Preparation
SOW - Special Operations Wing
SPOT - Système Probatoire d'Observation de la Terre
SSDB - Standard Simulator Data Base
STOW-E - Synthetic Theater of War-Europe
STRICOM - Simulation, Training and Instrumentation Command
TARDEC - Tank and Automotive Research and Development Command
TARGET - Training and Rehearsal Generation Toolkit
TDS - Terrain Decoration System
TEC - U.S. Army Topographic Engineering Center
TF\TA - Terrain Following/Terrain Avoidance
TIGER - Topographically Integrated Geographic Encoding and Referencing
TIN - Triangulated Irregular Network
TLM - Topographic Line Map
TMS - Terrain Modeling System
TPC - Tactical Pilotage Chart
TRSS - Training Support Squadron
TTADB - Tactical Terrain Analysis Data Base
TTD - Tactical Terrain Data
TUC - Transportation Use Category
UMC - Underlying Material Category
USAF - United States Air Force
USGS - United States Geological Survey
USSOCOM - United States Special Operations Command
UTM - Universal Transverse Mercator
VITD - VPF Interim Terrain Data
Vmap - Vector Smart Map
VPF - Vector Product Format
WDA - Water Depth Average
WES - Waterway Experiments Station
WGS - World Geodetic System
WST - Weapon System Trainer

PREFACE

This report was prepared under Contract DACA76-90-D-0001-0008 for the U.S. Army Topographic Engineering Center, Alexandria, VA 22315-3864 by PAR Government Systems Corporation, New Hartford, NY 13413-1191. The Contracting Officer's Representative was Mr. James Ackeret.

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EXECUTIVE SUMMARY

This study examined the following four synthetic environment terrain data base generation systems:

1. The U.S. Army Topographic Engineering Center (TEC), Digital Products Center (DPC) terrain Data Base Generation System (DBGS), supported by LNK Corporation, Alexandria, VA

2. The Close Combat Tactical Trainer (CCTT) terrain DBGS, operated by Evans & Sutherland (E&S), Salt Lake City, UT

3. The USAF 58th Training Support Squadron's Mission Training Support System (MTSS) terrain DBGS, operated by Lockheed Martin, Kirtland AFB, NM

4. The U.S. Special Operations Command's (USSOCOM) Special Operations Forces Aircrew Training System (SOF ATS) terrain DBGS, operated by Loral Defense Systems, Hurlburt Field, FL.

The first two systems produce terrain data bases to support U.S. Army networked ground vehicle simulation exercises, while the latter two produce terrain data bases for USAF SOF helicopter and aircrew training and mission rehearsal. All of these systems are basically similar in operation. They all use standard Digital Topographic Data (DTD) products, primarily Digital Terrain Elevation Data (DTED), Digital Feature Analysis Data (DFAD), and Interim Terrain Data (ITD), supplemented with a variety of imagery, cartographic, and other miscellaneous data sources. The front end of each system reads these sources, processes them to eliminate anomalies, and meets image generator data density constraints. This produces a representation of the terrain surface, 2-D features, 3-D models, and texture patterns. These are integrated into a single polygonal representation of the environment. The back end of each system uses this integrated representation to create various products, including image generator (IG) run-time data bases, radar simulator run-time data bases, semi-automated forces (SAF) run-time data bases, mobility data bases, and/or simulation maps.

However, in detail, these systems are all very different from one another, and their products, with the exception of interchange data bases in Standard Simulator Data Base (SSDB) Interchange Format (SIF) format, are not compatible with one another. The TEC DPC and CCTT terrain DBGSs usually construct relatively small data bases, on the order of 100 km by 100 km in extent, to support specific simulation exercises using primarily high-resolution (i.e., 1:50,000-scale equivalent) DTD sources. The integration of features (e.g. roads) into the terrain surface is a major concern. These data bases typically require 6 months to produce. The Mission Training Support System (MTSS) and SOF ATS terrain DBGSs construct much larger data bases, from 50,000 to 500,000 square nautical miles (nmi) in extent, using primarily medium-resolution (i.e., 1:250,000-scale equivalent) DTD sources, with small, embedded areas of high resolution, corresponding to navigation way points and target areas, built using the best available imagery. Features are normally draped over the terrain surface. Each system uses a

different representation of the terrain surface, uses a different set of software tools (though ARC/INFO and AutoCAD© are common to multiple systems), and produces run-time data bases for different types of IGs, supporting different polygonal representations of the synthetic environment.

DTD Problems, Requirements, and Issues:

The operators of these terrain DBGSs identified several problems with the use of current National Imagery and Mapping Agency (NIMA) DTD products as inputs to this process. In approximate order of importance, the most significant of these problems are:

1. The lack of availability of high-resolution standard DTD products is the most important problem that must be faced by synthetic environment terrain data base developers. Because high-resolution DTD products are not yet widely available, synthetic environment terrain data base generation systems must be capable of using a wide variety of alternative data sources, including various types of imagery and existing cartographic products, which greatly complicates the front end of these systems.

2. The significant amount of time and effort terrain data base developers currently spend correcting or eliminating consistency problems in the older DTD products, including poorly formed features, elevation anomalies, inconsistencies across cell or manuscript boundaries, and feature network connectivity problems.

3. The large amount of time and effort terrain data base developers spend attempting to integrate terrain elevation and 2-D feature information to create a realistic 3-D representation of the terrain. Simply draping features over the terrain surface does not meet the requirements of ground vehicle simulation applications. Roads must have reasonable pitch and roll angles in order for simulated vehicles to be able to drive over them, rivers must run downhill, and lake surfaces must be flat.

4. The problems caused by feature data organized in multiple thematic layers for synthetic environment terrain data base generation systems, which ultimately requires a single feature layer representing the appearance of the terrain. Correlation problems between features in separately produced thematic layers creates additional editing work for terrain data base developers. Even when the DTD is initially correlated, independent modification of features in different layers can easily create additional correlation problems.

5. Finally, existing and forthcoming DTD products do not contain all of the geometric and attribute information required for synthetic environment terrain data base generation. For synthetic environment terrain data base generation, each feature must include the geometric and attribute information necessary to support the reconstruction of the feature as a 3-D object. Specific problems arise at all locations where there is more than one significant elevation, such as bridges, overpasses, and tunnels. Also, while Feature and Attribute Coding Catalog (FACC) contains several attributes that deal with the material

composition of various types of features, there is currently no uniform method of determining the material composition of any feature or primitive in the newer Vector Product Format (VPF)- and FACC-based products.

Surprisingly, perhaps, the level of detail of the existing standard DTD products is not currently a problem, as much of the data contained in high resolution products, such as ITD, is currently discarded. There are two reasons for this: 1) many of the features and attributes, such as the ITD slope polygons, represent a symbolic, abstract representation of the real world that does not support the full-scale, 3-D nature of synthetic environments, and 2) the current performance of most real-time image generators cannot handle the density of information that the product contains. This does not mean that the information is not needed to address the requirements of simulation applications, only that it cannot be used in its current form, or in conjunction with current image generators.

From the above problems, several general requirements can be derived for standard DTD products that are to be used for synthetic environment terrain data base generation:

1. Synthetic environment applications involving the simulation of ground vehicles will eventually require "world-wide" DTD coverage at "Level 2" resolution (i.e., 1:50,000-scale equivalent)

2. Synthetic environment applications require DTD that is consistent, seamless, and free of anomalies

3. Synthetic environment applications require 3-D digital terrain elevation and feature data that is produced from the same source material, with the same level of accuracy, and is fully correlated

4. DTD products to be used for synthetic environment terrain data base generation must report all 3-D coordinate locations at the terrain surface, or must clearly indicate the relative height of each location above or below the terrain surface

5. Synthetic environment applications require DTD feature data in an integrated form, with a single topologically consistent layer, and with a high degree of relative accuracy between nearby features

6. DTD products that are to be used for synthetic environment terrain data base generation must contain sufficient geometric and attribute information to allow all features to be reconstructed as 3-D objects, and to be positioned correctly relative to all other nearby features

7. DTD products to be used for synthetic environment terrain data base generation must be capable of reporting multiple significant elevations at the same location, such as at bridges and overpasses, and must represent the true connectivity of the features that meet at (or pass through) such locations

8. DTD products to be used for synthetic environment terrain data base generation must provide surface material information for all features.

Several other issues also important to synthetic environment terrain data base generation are identified and discussed. The most important of these includes:

1. The traditional cartographic forms of abstraction, which are derived from the requirements of hardcopy map production, and the form of abstraction provided by synthetic environments, are clearly different, though related, with a common foundation in the tactical significance of terrain features. Much of the information contained in current DTD products cannot be used by synthetic environment terrain data base generation systems because it does not support the characteristics of the synthetic environment abstraction

2. That data quality metadata is neither updated nor transmitted by current synthetic environment terrain data base generation processes, making it impossible to evaluate the fidelity of the resulting synthetic environment terrain data bases. In the absence of metadata, visual comparisons of hardcopy maps and softcopy planimetric and perspective view displays are often used to compare input and output data bases

3. The variety of different terrain surface representations used by synthetic environment terrain data base developers is a major obstacle to interoperability

4. That real-time IG performance constraints currently dominate the synthetic environment terrain data base generation process. In order to meet polygon budget constraints, features are discarded, thinned and generalized, terrain elevation data is resampled, and the locations of both elevation posts and feature vertices are adjusted by "snapping" them to the boundaries of terrain modules that are sized to fit the memory management requirements of specific IGs. Also, the details of IG constraints interfere with the interoperability of run-time terrain data bases.

Synthetic Environment Terrain Requirements Framework:

With respect to ground vehicle simulation applications, synthetic environment terrain data base requirements can be organized according to the types of terrain-related operations that these simulations perform. These include:

- Sensor Simulation, which dynamically models, either symbolically or through the creation of synthetic imagery, those elements of the terrain that can be detected by various types of sensors, including:
  - Visual (Out-The-Window)
  - Infrared/Night Vision
  - Radar

• Movement Simulation, which dynamically models the movement of the simulated vehicle over the terrain

• Terrain Reasoning, which dynamically models the terrain-related decision-making performed by the crew, whether live or simulated, including two levels:

- Direct terrain reasoning, modeling the terrain-related reasoning of the crew concerning those elements of the terrain that can be directly viewed, using the output of the sensor simulators

- Symbolic terrain reasoning, modeling the terrain-related reasoning of the crew concerning those elements of the terrain that are not in direct view, using hardcopy maps or DTD.

These categories can be used as a framework for the organization of synthetic environment terrain data content requirements. In manned simulators, visual and sensor models are used to create synthetic imagers to be viewed by the crew. In SAF systems, more abstract models are used that determine which other entities and objects in the environment are detected.

A mobility model determines the maximum movement speed of a simulated vehicle, based on the characteristics of the terrain, vehicle, and driver. Mobility models, such as the NATO Reference Mobility Model - II (NRMM II), use soil type, soil moisture/strength, slope, surface roughness, and vegetation and obstacle characteristics.

In manned simulators, terrain reasoning is performed by the live crew. Direct terrain reasoning is performed in real time, based on the information available to them. It comes primarily through the visual and sensor displays of the simulator, and includes such activities as steering the vehicle and scanning for targets. Symbolic terrain reasoning is mostly performed before the exercise, using maps and their electronic equivalents, primarily for planning purposes. In SAF systems, terrain reasoning algorithms, which are still in the very early stages of development, access the synthetic environment data base to simulate these activities, using the polygonal, and in some cases, the vector, representations of the environment. SAF systems should never require more information, or different information, than their real counterparts, or corresponding manned simulators. However, SAF systems, because of their real-time performance constraints, may require the information to be organized differently, and to be simplified or more abstract. Also, SAF systems use both polygonal and vector representations of terrain data and require consistency between these different representations.

Recommendations:

The similarities and differences between traditional cartographic abstraction, based on the concepts of map scale and symbolic communication, and the forms of abstraction necessary to support full-scale, 3-D synthetic environment terrain data bases, should be investigated further in

order to identify which characteristics of DTD are most important to the creation of synthetic environments.

The impact of image generator constraints on the fidelity of synthetic environment terrain data bases should be investigated and quantified by comparing existing synthetic environment terrain data bases against the DTD sources used in their creation. This is complicated by the fact that synthetic environment terrain data bases use a variety of polygonal representations, while the DTD sources consist of gridded elevation data and vector feature data.

Of the existing and planned DMA DTD products, the Digital Topographic Data (DTOP) component of the Tactical Terrain Data (TTD) product comes closest to meeting the general requirements of synthetic environment terrain data base generation for ground vehicle simulation applications. This is primarily because of its derivation from stereo imagery sources, its use of 3-D coordinates, and its extensive feature and attribute content. However, it does not fully integrate the terrain surface and features, and does not provide feature information in an integrated manner, but rather, separates it into a larger number of thematic layers. Also, its feature and attribute content may actually be excessive for synthetic environment terrain data base generation in some respects, while remaining inadequate in others, since much of the information that it contains is still symbolic in nature, and does not necessarily provide the information needed to reconstruct 3-D representations of all terrain features.

It appears that the TTD production process could be adapted relatively easily to produce an additional product, in conjunction with TTD, that would greatly facilitate the generation of synthetic environment terrain data bases. Determining the feasibility of this recommendation requires:

1. Examining the TTD production process, the contents of the DTOP product, including its MEDS levels, and the FACC data dictionary, to determine their compatibility with synthetic environment terrain data base requirements

2. Developing extensions to the VPF standard to address its limitations relative to synthetic environment terrain data base generation, including:

- The integration of terrain elevation and 3-D feature information

- Support for a standard baseline representation of the terrain surface and 3-D features

3. Developing the design of a new DTD product, an additional output of the TTD production process, to specifically support synthetic environment terrain data base generation based on user profiles. This new product should include the following characteristics:

- Integrated 3-D features and terrain elevation information, in either a single coverage or the smallest possible number of coverages, extracted from stereo imagery sources

- A baseline triangulated irregular networks (TINs), including all of the 3-D vertices measured from the stereo imagery source, so that it is integrated with all features

- Features and attribute content based on the results of the recommended investigations of feature requirements for synthetic environments, DTOP/MEDS, and FACC.

1. INTRODUCTION

The purpose of this report is to examine the use of Digital Topographic Data (DTD) in the generation of synthetic environment terrain data bases. The goal of identifying enhancements to the current DTD formats and products of the National Imagery and Mapping Agency (NIMA) would facilitate the synthetic environment terrain data base generation process. This report is to be used as an educational tool for understanding any issues or problems with the four systems investigated in their production of SE run time data bases. The recommendations and conclusions are based on the observations of the study. The community can identify further investigations to resolve the most significant problems identified in the study.

Section 2 describes four synthetic environment terrain data base generation systems. It focuses on their use of current DTD formats and products, the data sources they use, the outputs they produce, the processing they perform, and the tools that are used to perform this processing. Management of the terrain data base generation process is briefly discussed, and problems encountered in the use of DTD formats and products are identified. It is not the purpose of this report to evaluate these synthetic environment terrain data base generation systems, rather to describe them so that their use of DTD may be properly understood, and their DTD requirements can be properly identified.

Section 3 discusses the most significant problems identified in the use of DTD in these systems, as well as several other issues related to the use of DTD in synthetic environment terrain data base generation, and derives several general requirements for DTD products that are to be used in synthetic environment terrain data base generation.

Section 4 describes a general framework for synthetic environment terrain data base requirements based on the products currently produced by synthetic environment terrain data base generation systems, addressing mobility, sensor simulation, and terrain reasoning, as well as visual image generation.

Section 5 summarizes the conclusions drawn, and makes recommendations for further investigations of several issues, as well as refinements to existing DTD formats and products to better facilitate the synthetic environment terrain data base generation process in the future.

Section 6 contains a list of references.

Appendix A summarizes the usage of Digital Feature Analysis Data (DFAD) and ITD features by two of the synthetic environment terrain data base generation systems described in Section 2, and identifies which features are included in synthetic environment terrain data bases and how they are represented.

2. SYNTHETIC ENVIRONMENT TERRAIN DATA BASE GENERATION PROCESSES

This section summarizes the characteristics of four different synthetic environment terrain data base generation systems, as implemented within the following organizations:

1. The U.S. Army Topographic Engineering Center (TEC), Digital Products Center (DPC), Alexandria, VA, supported by LNK Corporation

2. The U.S. Army STRICOM's Close Combat Tactical Trainer (CCTT) program, supported by Evans & Sutherland (E&S), Salt Lake City, UT

3. The USAF 58th Training Support Squadron's Mission Training Support System (MTSS), Kirtland AFB, NM, supported by Lockheed Martin, Loral, and Hughes Training

4. The U.S. Special Operations Command's (USSOCOM) Special Operations Forces Aircrew Training System (SOF ATS) Hurlburt Field, FL, supported by Loral Defense Systems.

Each of these systems is described below in terms of the input sources they use, the output products they produce, the processes performed and their general sequencing, and the tools used to implement these processes. Management aspects of the terrain data base generation process also are discussed, however specific schedule and cost information was not generally available. Specific problems and issues with respect to the use of DTD are identified. Within this overall description of each system, the primary focus is on the use of DTD, especially standard NIMA digital products. To the extent possible, the use of specific DTD features and attributes is identified.

The terrain data base generation processes are described graphically using a simplified form of the Integrated Definition for Function Modeling (IDEFO) notation. Processes are shown as boxes. Arrows coming into a box from the left represent the inputs to that process, while arrows going out of a box from the right represent the outputs of that process. Arrows entering the box from the top are controls, which determine how the process is to be carried out in a particular instance. Arrows entering a box from the bottom represent the tools or other mechanisms that implement the process. Diagrams can be hierarchically nested, with a lower-level diagram corresponding to a single box in the higher level diagram.

2.1 TEC DPC TERRAIN DBGS

TEC's DPC has been responsible for the development of a number of synthetic environment terrain data bases that have been used to support distributed simulation exercises using Simulator Network (SIMNET) simulators and other DIS-based systems. These include the Saudi Arabia, Kuwait, and Iraq (SAKI) data base developed in 1991-92, the Synthetic Theater of War-Europe (STOW-E) data base(s) developed in 1994, and the Chorwon (Korea) data base developed in 1994-95. The TEC DPC terrain data base generation process has evolved

significantly during this period to incorporate innovations such as the increasing use of microterrain and Triangulated Irregular Networks (TINs), the integration of roads and waterways into the terrain surface, and the use of a wider variety of cultural and natural features.

The information in this section is derived primarily from documentation describing the SAKI, STOW-E, and Chorwon data bases. These data bases, briefly described below, illustrate the evolution of the TEC DPC terrain data base generation process over the past several years.

SAKI Data Base

The SAKI data base, developed in 1990 over a period of approximately 6 months (July to December), with enhancements continuing through November 1991, covers all of Kuwait and parts of Saudi Arabia and Iraq. The dimensions of the data base are 360 km by 290 km. It uses a flat earth model based on UTM Grid Zone 38R. With the exception of DTED Level 1, no DTD sources were available to be used in the generation of this data base—features were digitized from SPOT-image maps, Landsat-image maps, Topographic Line Maps (TLMs), Joint Operations Graphic (JOGs), and, in a few cases, Tactical Pilotage Charts (TPCs) (vertical obstacles) and Operational Navigation Charts (ONCs) (water-bound obstacles).

The terrain surface consists primarily of 125-m right triangles, derived by resampling from DTED Level 1. The open water of the Persian Gulf consists of 500-m right triangles. The area along the coast is made up of microterrain polygons with an average edge length of 75 m, based on the coastline digitized from SPOT and Landsat image maps. Coastal facilities, such as piers and docks, are modeled using microterrain polygons with an average edge length of 50 m. Soil types are assigned to each terrain polygon.

The data base coverage area contains only limited vegetation. In general, surface features (e.g. swamps, grassland, crops) are mapped to a discrete set of terrain polygons, quantizing both the size and shape of such features to a significant degree. Individual trees are modeled using rotating tree stamps with a picture of a tree applied as a texture. Areas of rotary irrigated crops are modeled using a 500 m by 500 m pattern of microterrain polygons.

Roads and railroads are modeled using quadrilateral polygons of varying widths (based on road type), with triangles connecting the individual segments and textures (also based on road type). These road polygons are simply placed on top of the corresponding terrain polygons. Airfields are modeled as composites, with runways and taxiways consisting of 50 m-wide textured rectangular polygons (similar to roads). Hangars and control towers are represented as 3-D models.

Cultural features include:

- Key buildings, represented by specific 3-D models placed at specific locations
- Offshore oil platforms, represented by generic 3-D models placed at specific locations

- Powerlines, represented by generic 3-D tower models placed at 300 m intervals

- Oil installations, represented by collections of generic 3-D models

- Pipelines, represented by generic 3-D models placed in 100 m sections, placed on or beneath the terrain

- Power plants and substations, represented by generic 3-D models

- Villages, represented by generic 3-D models

- Radio and water towers, represented by generic 3-D models placed at specific locations and parameterized by height.

STOW-E Data Base

The STOW-E ground maneuver terrain data base, developed in 1994 over a period of approximately 6 months (April-October), covers the Grafenwoehr and Hohenfels training areas in Germany, as well as the surrounding area. Its dimensions are 64 km by 84 km. It is located in UTM Grid Zone 32U. Most of the source data was converted from WGS84 to European Datum 1950. Larger Air and Naval Operations terrain data bases were created for STOW-E, but these are not discussed here.

The terrain surface is modeled using a TIN created at Carnegie Mellon University (CMU) from DTED Level 2 and ITD transportation features (after thinning to remove cart tracks and minor roads, and editing to ensure connectivity). Because of image generator constraints, only the most important transportation features were integrated into the TIN surface.

ITD was the primary source of feature data where it was available. TLMs were digitized where ITD was not available, and were used as a secondary source to verify and enhance cultural features. SPOT imagery was used to verify the current disposition of features. Site survey photos and videos were used to support the shaping, coloring, and texturing of features.

Vegetation features were represented using S1000™ tree stamps, treelines, and canopies. The shapes and sizes of vegetation features were generalized to facilitate Semi-Automated Forces (SAF) vehicle movement. The area around Grafenwoehr is heavily forested, and canopies with concave shapes (i.e. cul-de-sacs) tend to trap SAF vehicles. Treelines were placed inside some canopies to reduce internal visibility.

Divided highways, primary highways, secondary highways, airfields, and some light duty roads were integrated into the terrain surface using road widths obtained from ITD. Railroads were modeled as quadrilateral and triangular polygons with texture patterns (railroad tracks on a transparent background), that were draped over the terrain polygons. Both roads and railroads were used to generate S1000™ networks.

Rivers, lakes, reservoirs, and other water bodies were added using surface and microterrain polygons that were attributed to indicate whether or not they were fordable. They were not integrated into the CMU TIN surface, but in some cases were integrated using the S1000™ load module TIN capability. Smaller rivers, streams and canals were used to generate S1000™ networks.

Cultural features included:

- Powerlines, represented using generic tower models, 45 m tall, placed at 300 m intervals, at locations digitized from TLMs

- Military reservation boundaries, digitized from TLMs as networks, were included in the simulation maps produced to support exercise participants

- Landmarks included military installations, towns and villages, forests, mountains, and rivers/canals

- Urban area outlines.

Chorwon Data Base:

The Chorwon data base was developed in 1994-95, over a period of approximately 6 months (October-April), to support the training requirements of the U.S. Eighth Army with respect to the Prairie Warrior exercise. The data base covers a 64 km by 80 km area in the Chorwon River Valley in South Korea, located in UTM Grid Zone 52U. Source data from TLMs were converted from the Tokyo Datum to WGS84.

The terrain surface is modeled using a TIN created at Carnegie Mellon University from DTED Level I. ITD transportation and hydrology features (after thinning and editing) were used to create the TIN surface. Some roads and open water bodies were integrated into the TIN surface. Because of the limitations of the CMU TIN generation software, open water bodies had to be manually extruded to make rivers run downhill. Rice paddy dikes, a significant feature in the data base coverage area, were generically modeled by hand and then incorporated into the terrain surface.

ITD was the primary source of feature data where it was available. Where ITD was not available, features were digitized from TLMs. SPOT imagery was used to verify the current disposition of features. Site survey photos and videos were used to support the shaping, coloring, and texturing of features.

Vegetation was represented using S1000™ tree stamps, treelines, and canopies. The sizes of vegetation features were reduced to facilitate SAF vehicle movement. Treelines were placed inside some canopies to reduce internal visibility. Agricultural areas (i.e., plowed fields) were represented by texturing terrain surface polygons.

Divided highways, primary highways, secondary highways, airfields, and some light duty and unimproved roads were integrated into the terrain surface, using road widths derived from ITD. Texture patterns were added to these polygons depending on road type. Railroads were modeled as rectangular polygons with texture patterns (railroad tracks on a transparent background), which were draped over the terrain polygons. Bridges were modeled as if they were dams or causeways. Ramps were created (similar to canopies). Both roads and railroads were represented as S1000™ networks. Smaller rivers, streams and canals were generated as S1000™ networks, and overlaid on the terrain surface as polygons. Demilitarized Zone (DMZ) boundaries were not used in the visual data base, however they were included in the simulation maps. Cultural features included:

- Powerlines, represented using generic tower models, 45 m tall, placed at 350 m intervals, at locations digitized from TLMs

- Landmarks included towns and villages, as well as major roads and rivers.

2.1.1 INPUT SOURCES

The TEC DPC terrain data base generation process integrates information from several different types of sources, including:

- DTD sources

- Imagery sources

- Cartographic sources

- Site survey sources.

Each of these is discussed below.

2.1.1.1 DTD Sources

The DTD sources used in the TEC DPC terrain data base generation process include:

- NIMA DTED

- NIMA DFAD

- NIMA ITD

- NIMA Tactical Terrain Data (TTD)

- U.S. Geological Survey (USGS) DEMs

• USGS DLGs

• Census Bureau Topographically Integrated Geographic Encoding and Referencing (TIGER) data.

NIMA DTD products, when available, are the primary sources for both terrain elevation data and most terrain features. DTED is the primary source for elevation data. ITD is the preferred source for feature data. DFAD is used only when no other source of feature data is available. TTD was recently implemented in a Camp Pendleton data base project. For locations within the U.S., USGS products, including DEMs and DLGs, and other DTD products such as Census Bureau TIGER files, also may be used as either alternative or supplemental sources.

NIMA DTED

DTED is the primary source of terrain elevation data. DTED Level 2 is preferred when it is available, and was used in the generation of the STOW-E data base. DTED Level 1 is used when DTED Level 2 is not available, and was used in the generation of the SAKI and Chorwon data bases. Special high-resolution DEMs, such as the Range 400 DEM, can be used. For the earlier SAKI data base, DTED Level 1 was resampled to create 125-m right triangles that were supplemented with microterrain along the coastline. For the more recent STOW-E and Chorwon data bases, DTED was used to generate TINs, into which some transportation and surface drainage features were integrated.

NIMA Interim Terrain Data (ITD)

When available, ITD is the primary source of terrain feature data. ITD was used as the primary source of feature data for the STOW-E data base, and was the primary source of feature data for the Chorwon data base (with some features being digitized from TLMs).

Not all of the ITD thematic layers are used in the TEC DPC terrain data base generation process. The usage of ITD thematic layers can be summarized as follows:

• Surface Configuration/Slope—Not used. ITD slope polygons are generally not consistent with the corresponding DTED (either Level 1 or Level 2), as geomorphic features are used in the definition of the slope polygons

• Vegetation— Primary source for vegetation features, where ITD is available. Used to create S1000™ canopies, treelines, and tree stamps

• Surface Materials—Some features in this layer are used to create textures, microterrain (e.g. rock outcrops), and to assign surface material mobility codes

• Surface Drainage—Primary source for surface drainage and other hydrography features, where ITD is available. Some features may be integrated into the terrain surface when a TIN is used

- Transportation—Primary source for road, railroad, bridge, tunnel, airfield, and other transportation-related features where ITD is available. Some features may be integrated into the terrain surface when a TIN is used. Also it is used to create S1000™ transportation networks and, when roads are not integrated into the terrain, overlay polygons

- Obstacles— Not generally used. This is a very diverse set of features whose actual occurrence is relatively rare. In particular, cut and fill features are not currently used in the integration of transportation features into the terrain surface.

ITD normally is supplemented with additional cultural features, digitized from 1:50,000-scale TLMs, that do not appear in any of the ITD thematic layers. Examples include powerlines, landmarks (significant buildings, monuments, etc.), and built-up areas.

Appendix A contains a set of tables summarizing the use of specific ITD features and attributes in more detail.

NIMA Digital Feature Analysis Data (DFAD)

DFAD Level 1 is not normally used in the TEC DPC terrain data base generation process because its resolution is not adequate for ground vehicle simulation. Nearly all other sources of feature data, including USGS DLGs, and digitizing features from imagery or higher resolution cartographic sources, are preferred over the use of DFAD. DFAD Level 2 has been successfully used, but the lack of standardized feature representation (e.g. buildings represented as linear features), as well as lack of availability, limits the usefulness of this product.

USGS DTD Products

USGS DEMs are essentially identical to NIMA DTED, therefore, are used as a substitute for DTED for locations within the continental U.S.

The 1:100,000-scale Digital Line Graphs (DLG-3) are commonly used as the source of vegetation, surface drainage, transportation, and other cultural features for locations within the continental U.S. when no acceptable NIMA product is available.

USGS Land Use/Land Cover (LULC) data is being used in the creation of the Southwest U.S. data base.

Census Bureau Products:

Census Bureau TIGER data have poor accuracy and consistency (e.g. roads frequently do not connect properly), and contain very little attribution. However TIGER data is sometimes used for locations within the U.S. when no other DTD source is available, as editing the TIGER data may be preferable to digitizing from either imagery or cartographic sources.

2.1.1.2 Imagery Sources

Imagery is used as a supplemental or alternative source when DTD is not available. Imagery is commonly used to verify, and if necessary, to update, the currency, accuracy, and completeness of DTD sources. The imagery sources that have been used in the TEC DPC terrain data base generation process include:

- SPOT imagery
- Landsat imagery
- National High Altitude Photography (NHAP)
- Other sources of similar digital imagery.

Digital imagery sources are used to create orthorectified images from which features can be digitized. Imagery is used as a source of geospecific texture, color information, and other appearance-related attributes, and may be used as an aid in the positioning of 3-D models corresponding to cultural features. Digital imagery may be used to create digital elevation models (DEMs), though it is usually possible to find a source of digital terrain elevation data (e.g. USGS or NIMA). Image control is a significant concern, as the orthorectification of imagery is a time consuming process. Although simpler image control methods could probably be used successfully, imagery is normally used as a source only in areas where very high accuracy is required, therefore it is felt that orthorectification is necessary, particularly for ground vehicle simulation applications. It is hoped that NIMA's Controlled Image Base (CIB), which will initially be derived from SPOT imagery, will become the primary imagery source.

2.1.1.3 Cartographic Sources

Cartographic sources (i.e., hardcopy maps) are used as alternative and/or supplementary sources of feature data, particularly when no DTD is available. Cartographic sources are used as visual references to help in interpreting the content of DTD and/or imagery sources. In spite of their poorer accuracy, cartographic sources, if current and available, may be preferred over imagery sources when time takes priority over quality. Digitizing features from cartographic sources can be accomplished more quickly and easily than first orthorectifying source imagery and then digitizing features from the orthorectified images. The types of cartographic sources that have been used in the TEC DPC terrain data base generation process include:

- 1:24,000-scale USGS 7.5' Quadrangle Maps
- 1:50,000-scale NIMA TLMs, which are generally the preferred cartographic source
- 1:50,000-scale NIMA Tactical Terrain Analysis Data Base (TTADB) overlays, though most of these have already been converted to ITD

- 1:50,000-scale SPOT Image Maps
- 1:100,000-scale Landsat Thematic Mapper Image Maps
- 1:250,000-scale NIMA Joint Operations Graphics (JOGs)
- 1:500,000-scale Tactical Pilotage Chart (TPC)
- 1:1,000,000-scale Operational Navigation Chart (ONC).

The smaller scale maps are used primarily for visual references in interpreting the contents of DTD and imagery. However, for the SAKI data base, JOGs, TPCs, and ONCs were used as the source for specific types of features, such as vertical obstacles and ocean-based oil facilities.

Other miscellaneous maps, including various tourist guides and maps, also may be used, when available, particularly for visual reference information on local landmarks.

2.1.1.4 Site Survey

A site survey is a standard part of the TEC DPC terrain data base generation process whenever access to the data base coverage area, and time, permits. When denied areas are to be modeled, unclassified photographic sources are frequently used as an alternative. Ground-level point-of-view information is collected on key landmarks and other features. This information is used in the creation and placement of specific 3-D models, as well as to provide general visual reference information (colors, textures, etc.) for the area. Ground control information also may be collected, but this must be done very carefully to avoid serious consistency problems when site survey information is combined with data from other sources. Available maps (or DTD) are used to plan the site survey in advance, to the extent possible, identifying key landmarks and other sites that should be visited, photographed and/or videotaped. Some time during the survey must be reserved for visiting additional, unplanned locations. Liaison with local personnel who know the area is vital to the successful identification of the critical landmarks, and the specific attributes that are most important for their recognition.

2.1.2 OUTPUT PRODUCTS

The set of output products from a particular TEC DPC terrain data base generation project is determined primarily by the specific format and media requirements of the simulators that will be used by the exercise participants, that are, in turn, determined by what image generator(s) they use and what input device(s) they have available. The types of output products may include:

- Terrain data bases of several different types, including:
  - Data bases in widely used interchange formats such as S1000™

- Run-time data bases in specific image generator (IG) formats
- Run-time data bases in specific computer generated forces (CGF) or SAF formats

- Simulation maps (SimMaps), which are 1:50,000-scale hardcopy maps similar to TLMs, but reflect the actual contents of the terrain data base
- Video release notes, providing an overview of the terrain data base in the form of a flythrough.

Each of these types of products is described briefly below.

2.1.2.1 Terrain Data Bases

The TEC DPC terrain data base generation process is capable of producing terrain data bases in a variety of run-time and interchange formats, for use by users with a wide range of hardware and software capabilities. S1000™ is the baseline format used. Other formats are each "compiled" from the S1000™ baseline. The types of formats supported include:

- Visual simulation data base interchange formats, including:
  - S1000™
- Specific image generator (IG) formats, including:
  - Those required by the SIMNET 120T/120TX/TXT and GT100 series image generators
  - Those required by SGI-based image generation systems such as Loral's Vistaworks™ and MultiGen™
- Specific CGF or SAF formats, including:
  - Those required by the SIMNET SAF 0400 and MCC systems
  - Various versions of the Compact Terrain Data Base (CTDB) format used by the ODIN SAF system and by different versions of the Modular Semi-Automated Forces (ModSAF) system. Formats 1 and 2 consisted of multiple files. Format 3, released with ModSAF Version 1.5, consolidated all terrain data base information into a single file with the extension .ctb, and supports big endian UNIX processors. Format 4, released with ModSAF Version 2.0, incorporates some of the capabilities developed under the CTDB project.

These data bases can be distributed on a variety of different types of magnetic media, including 1/4 inch, 4mm, and 8mm tape cartridges, and in some cases, can be transmitted directly over network links to the users.

2.1.2.2 Simulation Maps (SimMaps)

SimMaps are hardcopy maps produced and distributed to the simulation exercise participants as a substitute for the actual 1:50,000-scale TLMs that they would normally use when deployed in that area. The SimMaps reflect only the features contained in the synthetic environment terrain data base so that the exercise participants will not be confused by hardcopy map features that were not included in the terrain data base because of IG data base size or polygon density constraints. The SimMaps are initially output as plots for checking purposes. The final output form is a set of color separates that are used to produce large numbers of map copies.

2.1.2.3 Video Release Notes

Video release notes are produced and distributed, when time allows, as a means of helping users of a terrain data base familiarize themselves with its content. One or more scenes and/or fly-throughs of the data base are created using a perspective view display system (i.e., a "stealth" display).

2.1.3 PROCESS

As shown in Figure 1, the TEC DPC terrain data base generation process consists of seven major phases:

1. Project Preparation, in which requirements and deliverables are defined, source data availability is analyzed, the data base is designed, and the project is planned

2. Data Acquisition, in which source data is obtained and evaluated, a site survey is conducted, and imagery and cartographic sources are digitized

3. Data Analysis & Fusion, in which terrain elevation and feature data are preprocessed, and 3-D models are constructed

4. Data Base Population, in which the S1000™ data base is created, populated with terrain surface elements, features, 3-D models, and tested

5. Data Base Compilation, in which run-time and interchange data bases in various specific formats are created from the S1000™ data base

6. Data Base Distribution, in which the products are field tested, archived, copied, and transmitted to users

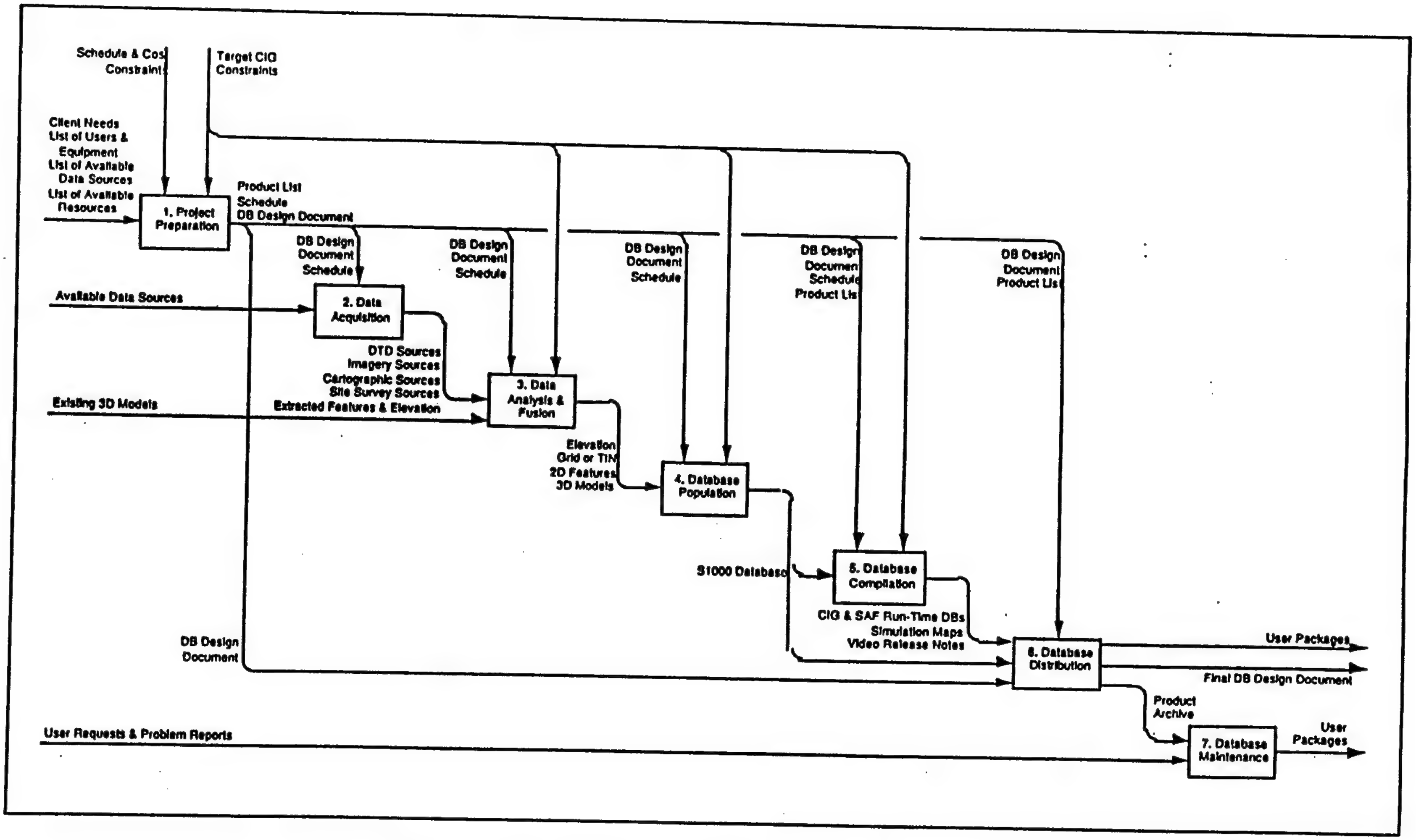

Figure 1. TEC DPC Terrain DB Generation Process

7. Data Base Maintenance, in which user support is provided, additional release requests and problem reports are processed, and configuration management is performed as corrections are made.

This is a very comprehensive process that covers not only the terrain data base generation process itself, but also preliminary and follow-up activities. The first two phases are concerned with preliminary activities. The next three phases: Data Analysis & Fusion, Data Base Population, and Data Base Compilation, form the heart of the data base generation process. The last two phases are concerned with follow-up and support activities. It should be noted that these phases are not entirely sequential, and overlap to varying degrees. Each of these phases is discussed in more detail in the following subsections.

2.1.3.1 Project Preparation

This phase consists of preliminary activities which are performed before the actual data base generation process begins. These activities include:

- Determining Requirements in which meetings are held with the customer to determine the requirements that the data base must meet, including the geographic location, size, and content of the data base

- Identifying Deliverables in which the different types of products that must be delivered are identified, the number of copies of each product needed is determined, and the media requirements of each user are identified

- Analyzing Source Availability in which the available data sources of various types for the data base coverage area are identified and prioritized

- Planning a Project in which the activities making up the data base generation process and their dependencies are defined, resources, including people and equipment, are assigned to these activities, and an initial schedule is created

- Creating a DB Design Document in which an initial version of the data base design document is created, which documents the data base requirements and basic design decisions.

The relationships among these activities, and their inputs and outputs, are shown in Figure 2.

2.1.3.2 Data Acquisition

This phase is concerned with obtaining, evaluating, and preparing the various types of source data for the data base generation process. The activities that make up this phase include:

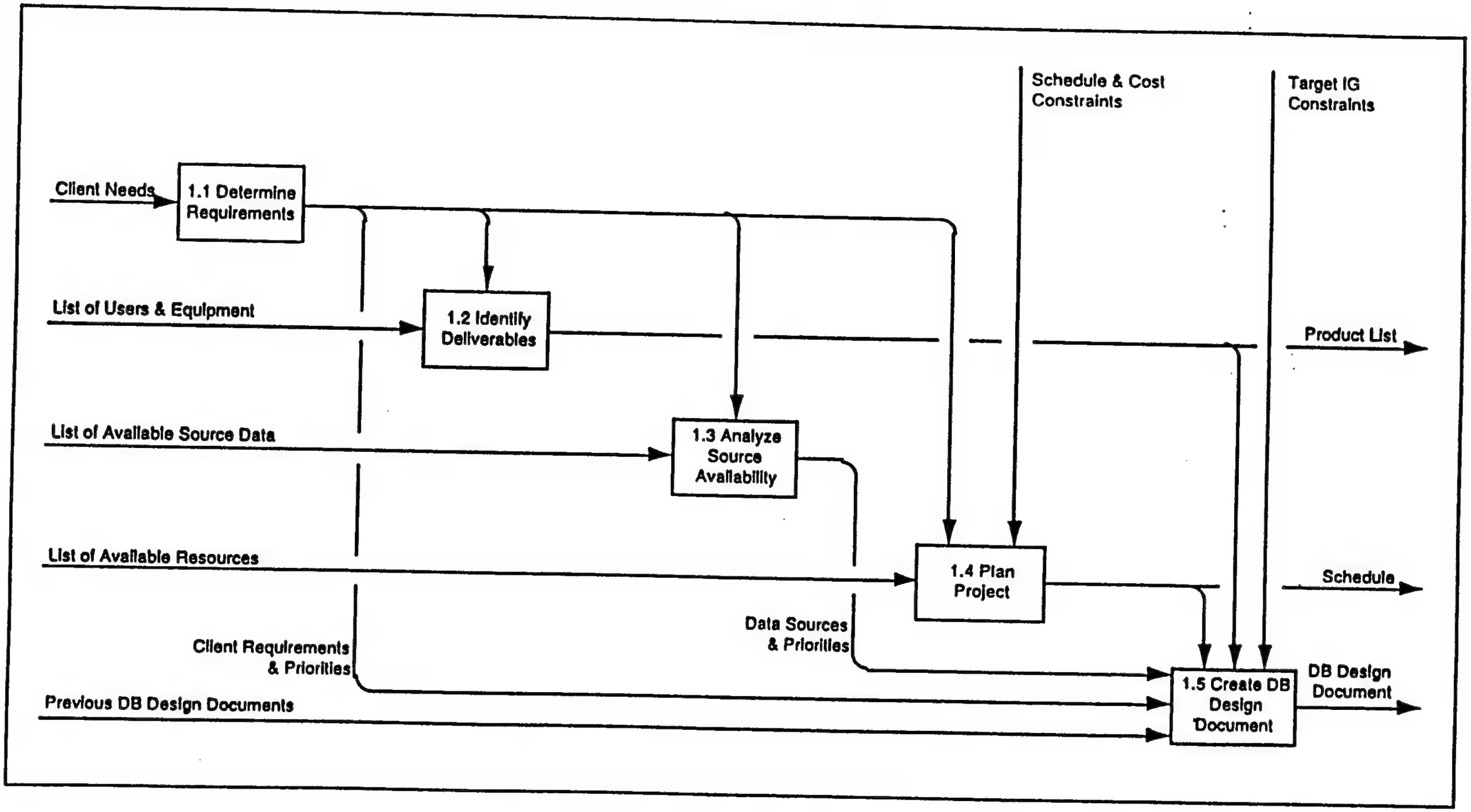

Figure 2. Project Preparation

• Obtaining Source Data, in which all available DTD sources, imagery sources, and cartographic sources for the data base coverage area are obtained from various sources

• Conducting a Site Survey, in which personnel visit the data base coverage area to collect information on landmarks and other key features, as well as the general appearance of the area (vegetation and soil colors, typical buildings, etc.)

• Evaluating Source Data, in which the quality and suitability of the various data sources are judged, and the usage of the different types of sources are prioritized

• Digitizing Image/Carto Sources in which hardcopy imagery and cartographic sources are scanned and orthorectified, if necessary, and then digitized to create vector feature data.

The relationships among these activities, and their inputs and outputs, are shown in Figure 3.

2.1.3.3 Data Analysis & Fusion

This phase involves the preprocessing of feature data in vector form and elevation data in matrix form, and the construction of 3-D models from site survey photos and videos, and other sources. The activities that make up this phase include:

• Preprocessing DTD Features in which feature data is imported into ARC/INFO, filtered, thinned, edge matched, generalized, buffered, translated, datum shifted and edited, as necessary, to create a set of correlated feature layers, and exported in ADDWAMS format from ARC/INFO to S1000™

• Preprocessing DTED, in which individual DTED cells are merged and edge matched

• Generating Land Surface in which either a TIN is constructed from the elevation grid, possibly with selected features, such as roads and rivers integrated into the TIN surface, or a right triangle terrain surface grid is created using the S1000™ Land Tool

• Creating 3-D Models in which 3-D models of specific and/or generic structures, such as buildings, bridges, towers, etc., are created using the S1000™ Model Tool and/or other CAD tools such as AutoCAD.

The relationships among these activities, and their inputs and outputs, are shown in Figure 4.

The ARC/INFO GIS system is used to perform a number of different operations on feature data. Because of image generator constraints, the number of features and vertices in high resolution sources, such as ITD, must be reduced. This is done by filtering out lower priority

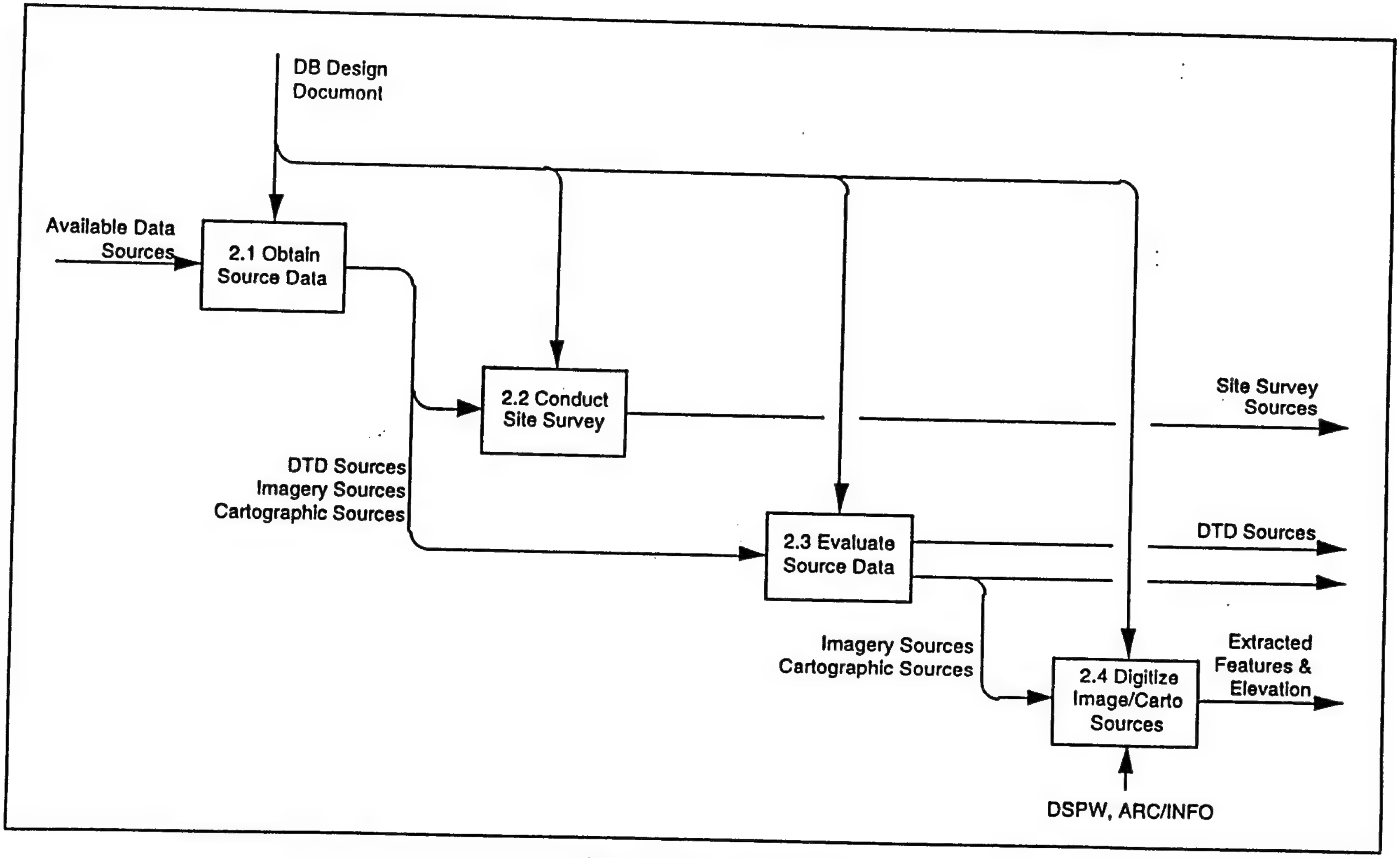

Figure 3. Data Acquisition

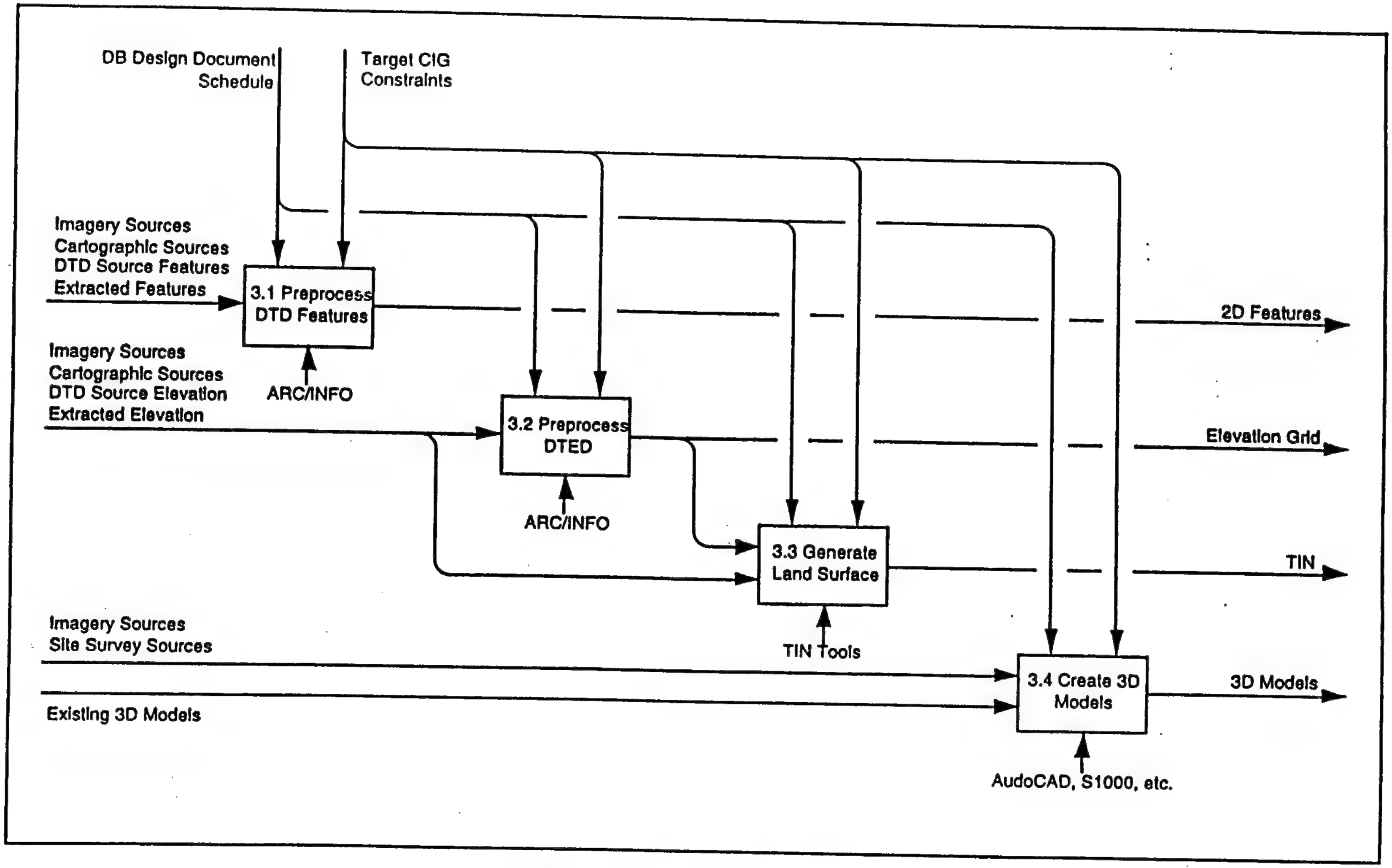

Figure 4. Data Analysis & Fusion

feature classes, such as cart tracks, thinning overall feature density by eliminating individual features according to various criteria (e.g. road width or class, dead-end roads), and generalizing individual features to reduce the number of vertices that they contain. A generalization tolerance of 15 m is typical.

The data reduction process is primarily based on rules of thumb from past experience. Urban areas usually present the highest feature densities, thus, are typically the most simplified. Other typical operations include edge matching features across cell boundaries, buffering around linear features, such as roads, where they pass through area features such as forests, translation of feature codes and attributes, and converting coordinates to the projection and datum specified in the user requirements. Macros, written in the ARC Macro Language (AML) are used to automate this process as much as possible.

In general, these activities are performed in parallel. However, if selected features are integrated into the terrain surface, then the preprocessing of these features must be completed before the land surface can be generated.

2.1.3.4 Data Base Population

In this phase an S1000™ data base is created and populated with terrain surface data, features, and 3-D models. The activities that make up this phase include:

- Creating a data base in which an "empty" S1000™ terrain data base is created, using the S1000™ Assembly Tool

- Populating a Land Surface, using the S1000™ Land Tool, in which either a terrain elevation grid is imported, projected to UTM coordinates and resampled, and used to generate land surface polygons consisting of a regular array of right triangles, or a TIN is imported and used to generate land surface polygons

- Populating Features, using the S1000™ Overlay Tool, in which groups of features are imported and used to create both vector and polygonal components of the S1000™ data base. Features can be imported in four different ways:

— Networks—feature layers containing networks of features, such as roads, railroads, and streams, are brought into S1000™ and used to create both vector networks and polygonal representations

— Canopies/Treelines—area features corresponding to forests and linear features defining treelines are brought into S1000™ and used to create canopies and treelines

— Ground Area Features—area features representing other types of ground features, such as lakes, swamps, brushland, etc., are brought into S1000™ and are used to assign soil types, colors, and/or textures to land polygons

— Site-Specific Features—point features are brought into S1000™, one at a time, and are used to position both specific and generic 3-D models

- Populate Models, using the S1000™ Model Tool, in which both specific and generic 3-D models are brought into S1000™

- Data Base Testing, in which the contents of the S1000™ data base are visually reviewed to identify any visual anomalies, and load modules are checked against polygon density constraints.

The relationships among these activities, and their inputs and outputs, are shown in Figure 5.

2.1.3.5 Data Base Compilation

Once an S1000™ data base has been created and populated, the activities that make up this phase use that data base as a source to create a number of different types of products, as specified by the user requirements. Because this is largely a translation process, and the resulting products are largely formatted for specific target systems, the tools that create these products are commonly called "compilers." The activities in this phase include:

- Compiling Image Generators (IG) data base(s), in which run-time data bases formatted for specific IGs are created from the S1000™ data base

- Compiling SAF data base(s), in which run-time data bases formatted for specific SAF systems, such as ModSAF, are created from the S1000™ data base

- Producing Simulation Maps, in which feature data exported from S1000™ back to ARC/INFO are used to create plots, and, after review, color separates, which are used to print 1:50,000-scale maps of the simulation data base, use the format of a 1:50,000-scale TLM

- Creating Video Release Notes, in which flythroughs of an Image Generator (IG) run-time data base are recorded, along with narration, to provide an introduction and overview of the data base to familiarize users with its contents

- Product Testing, in which the various products created, in the activities listed above, are tested to verify that they have been correctly produced.

The relationships among these activities, and their inputs and outputs, are shown in Figure 6.

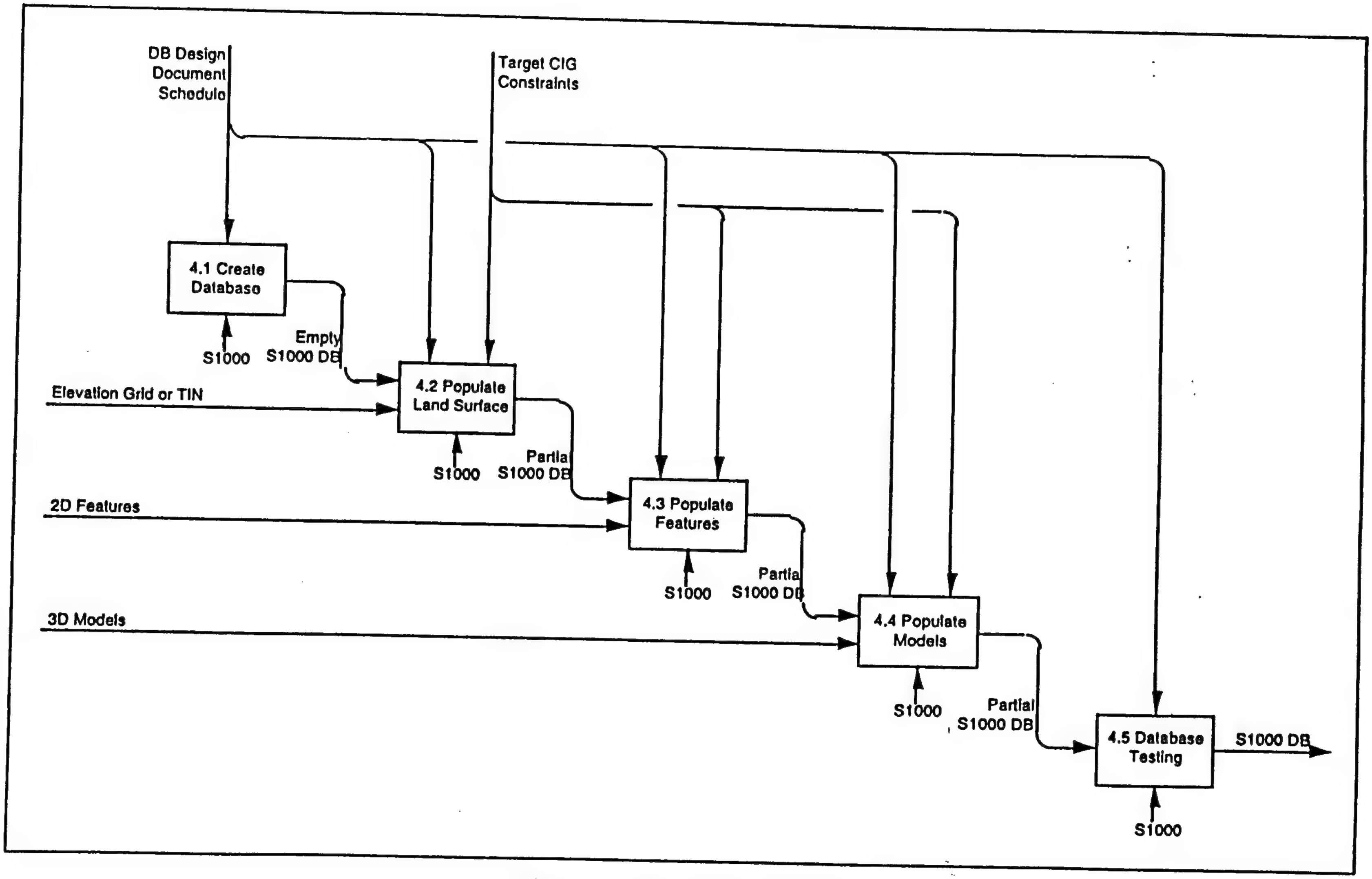

Figure 5. Data Base Population

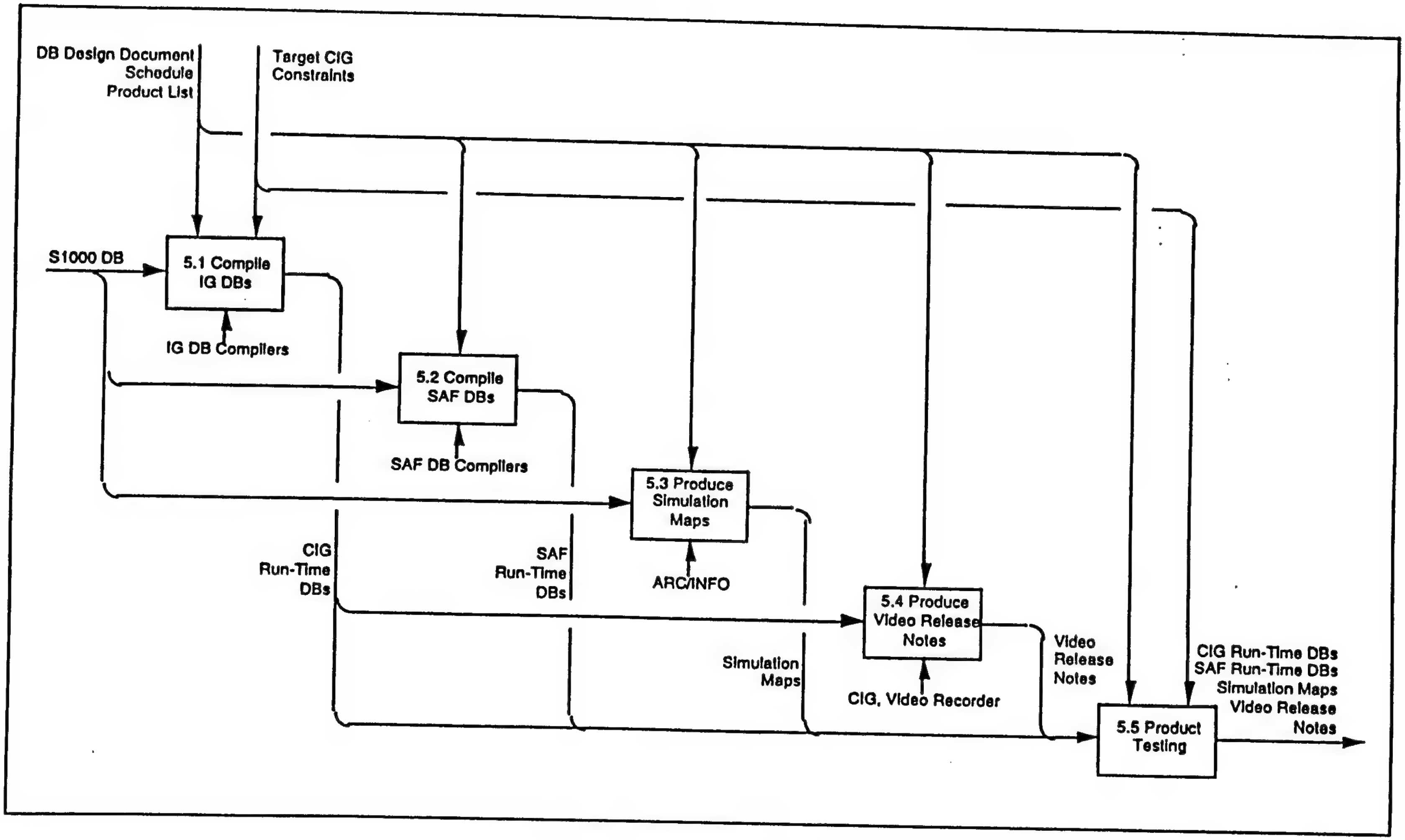

Figure 6. Data Base Compilation

2.1.3.6 Data Base Distribution

This phase is concerned with the distribution of the various terrain data base products to the users. This includes the following activities:

- Field Testing, in which products are sent to selected sites for testing before general distribution

- Updating DB Design Document, in which the initial data base design document is updated to incorporate any changes, additions, or other modifications

- Archiving Products, in which master copies of all of the products created by the project are archived

- Copying Products to Distribution Media, in which distribution copies of the products are generated, using the media types that can be accepted by each user

- Transmitting User Packages, in which the appropriate products are either physically or electronically transmitted to each user.

The relationships among these activities, and their inputs and outputs, are shown in Figure 7.

2.1.3.7 Data Base Maintenance

This phase includes any activities that follow the distribution of products to the users, including:

- Processing Release Requests, in which additional requests for previously released products are handled

- Processing Problem Reports, in which reports of data base anomalies or other problems are handled

- Performing Configuration Management, in which modifications to the data base are carried out and products are updated.

The relationships among these activities, and their inputs and outputs, are shown in Figure 8.

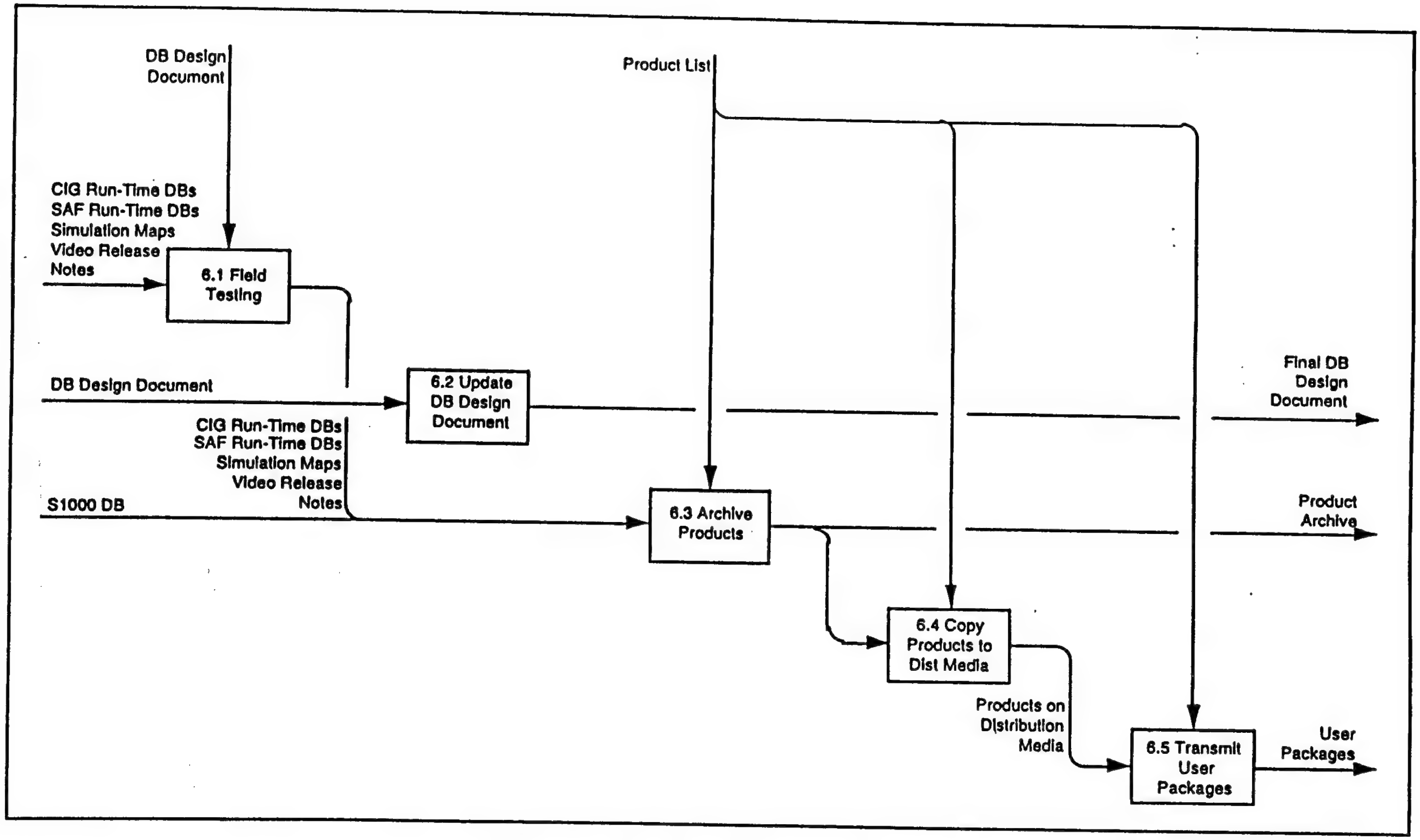

Figure 7. Data Base Distribution

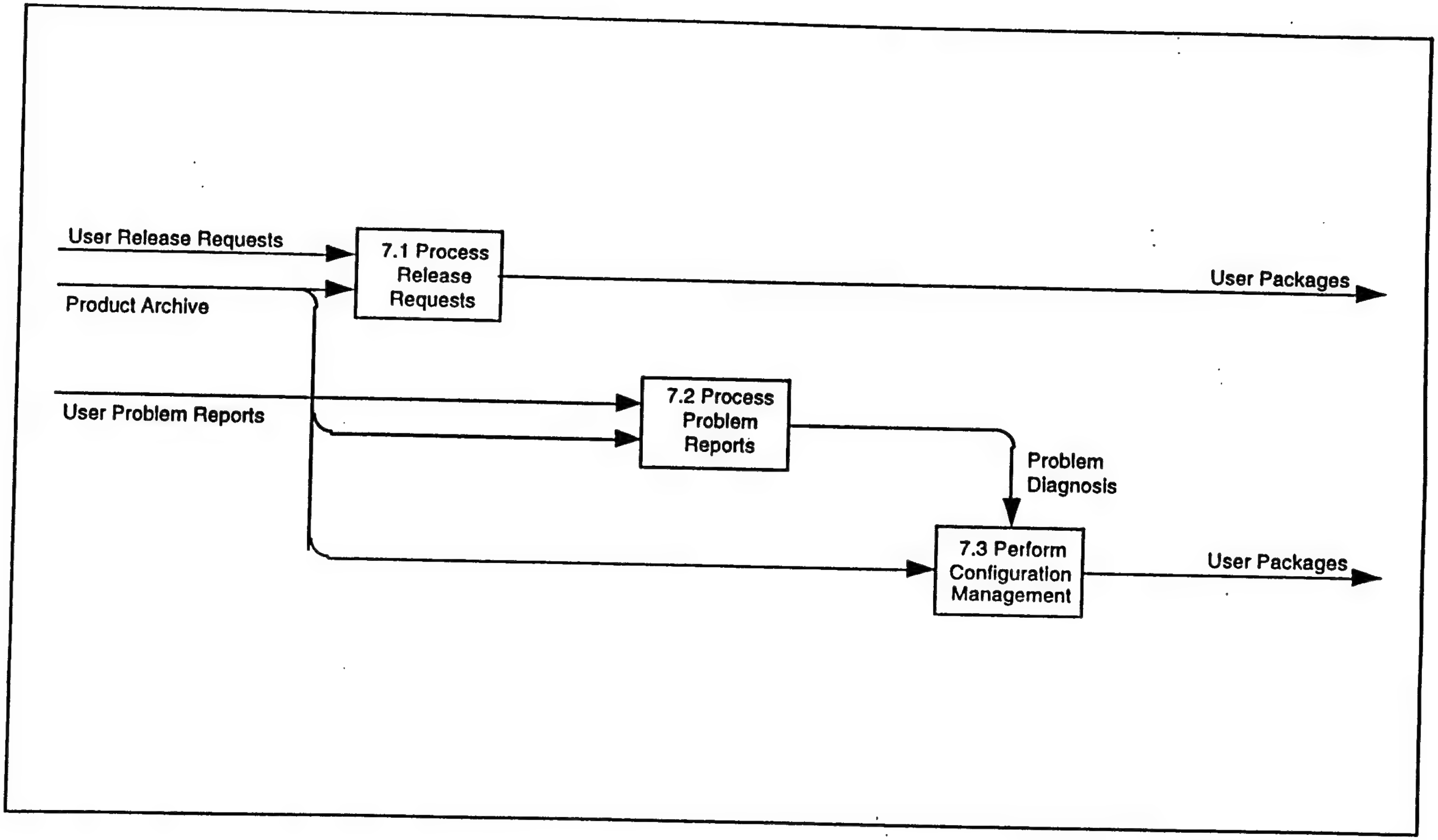

Figure 8. Data Base Maintenance

2.1.4 TOOLS

The principal tools used in the TEC DPC terrain data base generation process include:

- The Digital Stereo Photogrammetric Workstation (DSPW), developed by General Dynamics Engineering Systems, Inc. (GDE), which is used for image processing, ground control, orthorectification, and digitizing of features from imagery sources

- The ARC/INFO geographic information system (GIS), a commercial product of ESRI, running on Sun workstations, which is used in support of area selection and requirements definition, projection and datum definition, evaluation of available DTD sources, importing and datum conversion of feature data from various sources, feature code and attribute translation, filtering, thinning, generalizing, edge matching, buffering, editing, and exporting of feature data to S1000™ using ADDWAMS format

- TIN generation software, developed at CMU, which is used to create a TIN representation of the terrain surface from preprocessed DTED and selected features, which are to be integrated into the terrain surface (ARC/INFO TINs and the NIST TIN packages also have been used, but the CMU TIN generation software is preferred)

- The S1000™ data base generation tool set, developed by Loral Advanced Distributed Simulation. It runs on SGI workstations, which are used to create 3-D models of various types of specific and generic point features (Model Tool), to import a terrain elevation grid, or a TIN, and creates land surface polygons (Land Tool) to import transportation and surface drainage features to create S1000™ networks. It also imports vegetation features to create S1000™ canopies and treelines, imports ground area features to create land polygon soil types, colors and/or textures, and imports point features to locate and orient 3-D models (Overlay Tool), and integrates these elements into an S1000™ data base (Assembly Tool)

- AutoCAD™ and other commercial CAD tools that are used to create 3-D models

- A variety of data base compilers, which convert from S1000™ data base format to various specific IG formats, such as Vistaworks™, GT100 series, and MultiGen® OpenFlight™, SAF, and interchange formats, developed by a number of different organizations.

The relationships among these tools, and how they fit into the data base generation process, are shown in Figure 9.

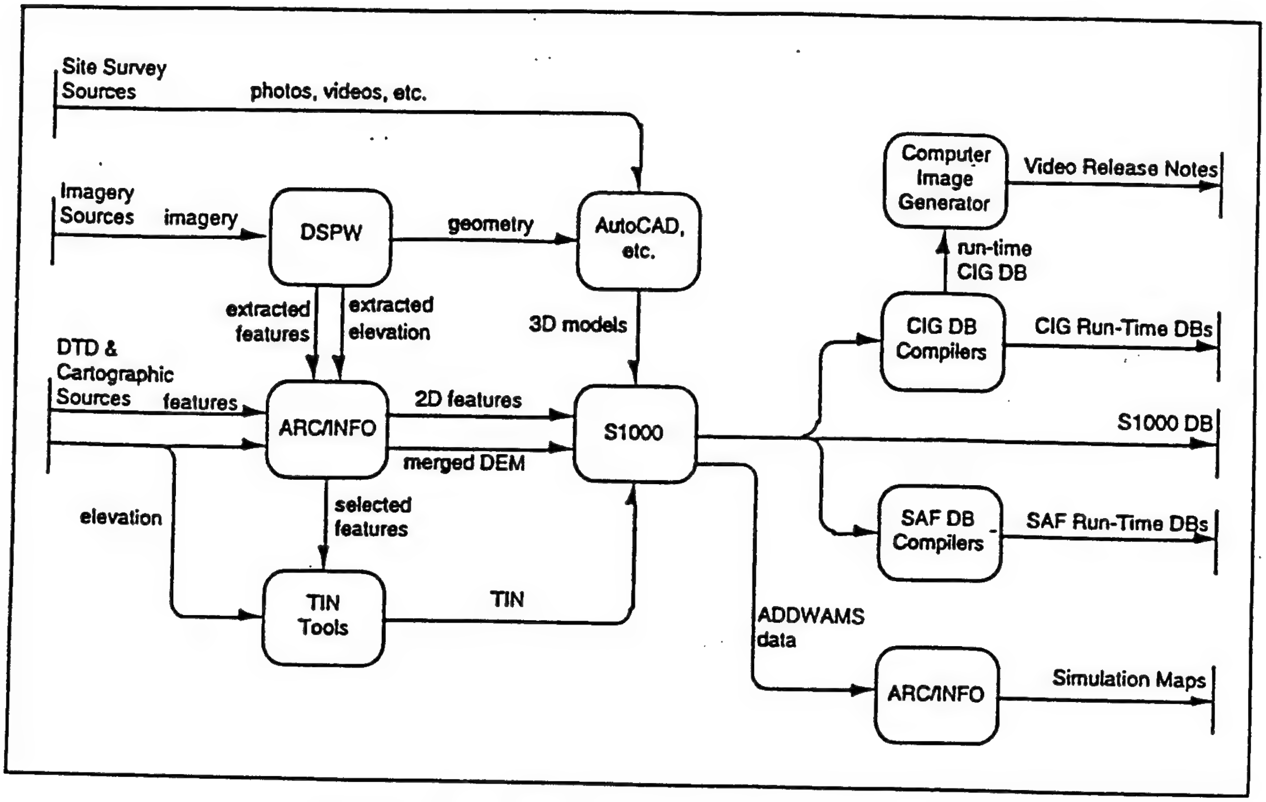

Figure 9. TEC DPC Terrain DBGS Data Flows

2.1.5 MANAGEMENT

A typical TEC DPC synthetic environment terrain data base generation project is between 3- to 6-months in duration. Planning and scheduling are based primarily on past experience with similar projects. The terrain data base generation process is well understood, and a formal process model is currently being defined.

All data analysis and fusion work, using ARC/INFO, which includes feature thinning, generalization, edge matching, and editing to correct errors and inconsistencies, is usually performed by a single experienced operator in order to achieve the most consistent possible results. Data base population work, using S1000™, which includes the creation of 3-D models, and the conversion of terrain features into S1000™ networks, pole-sets, and microterrain polygons, is typically performed by 4-6 operators working in parallel. These two phases can be performed in parallel to some degree, with 3-D models being built while feature data is being preprocessed.

2.1.6 PROBLEMS & ISSUES

Significant problems and issues identified by the operators of the TEC DPC terrain data base generation system include:

1. The limited availability of high-resolution (1:50,000-scale) DTD sources results in the requirement for the system to be able to make use of a wide variety of other sources, including both imagery and cartographic sources in hardcopy and/or digital forms. The orthorectification of imagery sources is particularly time consuming

2. The data consistency problems in the DTD sources, such as the misclassification of roads and other feature types (that do not always match the corresponding hardcopy maps), adds a great deal to the feature preprocessing workload. It was noted that features digitized from imagery using DSPW also exhibit inconsistencies in feature classification and attribute values, and that the data extraction process is highly operator dependent

3. The lack of correlation between the terrain elevation data and features results in a great deal of additional work being done to integrate features into the terrain surface. The ideal DTD product for synthetic environments would include 3-D features integrated with the terrain surface

4. The SIMNET image generator constraints having a number of impacts on the terrain data base generation process. SIMNET terrain data bases may be no larger than 50 mb, which typically is equivalent to approximately 5000 km^2. The SAKI Data Base was constructed in three sections (west, center, east) because of this constraint

5. The S1000™ has a number of limitations and constraints that impact the data base generation process, including:

- Its quadtree indexing structure, until recently, limited the size of an S1000™ Data Base coverage area to 256 km by 256 km (this has now been made somewhat more flexible by allowing load module size to be traded off against elevation post spacing, though the maximum number of polygons in a quadtree node is still limited to 2,100)

- The small size of load modules (500 m)—TINs are clipped to load module boundaries, creating large numbers of additional triangles; anomalies along load module boundaries are relatively common, with different types of anomalies associated with different types of features

- Fixed elevation grid density—when multiple elevation data sources with different resolutions are used in a data base, ARC/INFO must be used to merge the different resolution grids

— There is no direct path for importing most DTD feature sources, such as ITD, into S1000™— ARC/INFO, and ADDWAMS formats must be used as intermediate forms.

2.2 CCTT TERRAIN DBGS

The U.S. Army Simulation, Training, and Instrumentation Command (STRICOM) Close Combat Tactical Trainer (CCTT) program is developing and manufacturing a large number of networkable simulators for M-1 Abrams tanks, M-2 and M-3 Bradley infantry fighting vehicles, High Mobility Multipurpose Wheeled Vehicle (HMMWVs), and other types of U.S. Army vehicles. As part of the CCTT program, two primary terrain data bases are being constructed by E&S in Salt Lake City, UT: the "Central U.S." data base, which uses European terrain source data in conjunction with generic 3-D models typical of the midwestern U.S., and the "Desert" data base, which uses source data from the southwestern U.S. The "Central U.S." data base was to be completed by the end of 1995, with the "Desert" data base following in the first half of 1996. These data bases are briefly described in the following paragraphs.

"Central U.S." Data Base

The CCTT "Central U.S." data base covers an area approximately 100 km by 150 km, nominally located in the midwestern U.S. The terrain data used in this data base is actually for an area in central Europe, with the original coordinates used without alteration. The 3-D models used with this data base are typical of buildings and other structures that would be found in the midwestern U.S.

The data base is organized into a 14 by 20 array of square "parcels," each of which measures 7,680 m on a side. The parcel is the basic unit of memory management for the ESIG-HD/3000 image generator, and the content of each parcel is constrained by memory limits. In the CCTT data bases, each parcel is made up of an 8 by 8 array of "modules," each of which is 960 m on a side. There are a total of 280 parcels in each data base, and a total of 16,799 modules in the "Central U.S." data base and 16,485 modules in the "Desert" data base (where some parcels along the exterior are incomplete).

The terrain surface is modeled using a multilevel grid structure derived from DTED Level 2. Initially, the terrain surface within each module is defined by a regular array of 60 m right triangles. The ESIG-HD/3000 is a "hybrid" image generator that has the capability of processing the separating planes used in cellular priority as well as fixed listed objects and R-buffered models and objects. However, in general, the terrain surface is divided in a regular manner. Depending on optimization parameters derived from measurements of the local terrain roughness in each module, these initial facets may be combined, with groups of eight equal-sized triangular facets covering a square area being replaced by a pair of larger triangular facets. The resulting terrain surface consists of a mixture of right triangles, with sizes of 60 m, 120 m, 240 m, and 480 m.

ITD was the primary source for surface material, surface drainage, vegetation, transportation, and obstacle features. DFAD was used as a secondary source, primarily for cultural features missing from ITD, such as point features in rural areas, urban area variety, and powerline towers.

Vegetation is represented using 2-D and 3-D models. Forested areas are represented using irregular arrays of tree models of different types (representing deciduous, evergreen, and mixed forests), with an underlying ground texture pattern that gives the illusion of greater tree density when seen from a distance. Basis sets (collections of generic models) are used to model forested area facets efficiently. One or more basis sets are generated for each size, orientation, and type of forested area facet. These basis set models are then used to populate all of the similar facets within the data base. Ground vegetation (grass, etc.) is represented using standardized texture patterns. Area features are "snapped" to fit the triangular structure of the terrain surface, such that each triangle contains a single type of vegetation. This reduces the number of polygons required to represent the features, contributes significantly to the consistency of features, and allows more basis sets to be used.

Transportation features, including highways, railroads, and the associated bridges and tunnels, are integrated with the terrain surface using a cut and fill technique, based on parameters that specify the maximum allowable slopes of these feature segments. Fills are built on top of the triangular terrain facets, while cuts actually break the surface of the triangular facets into smaller polygons. Bridges and tunnels are inserted automatically according to specified criteria (e.g. a bridge is inserted wherever a highway and a stream intersect). Bridges, overpasses, road intersections and railroad crossings are represented using 3-D models, which are inserted into the data base at the appropriate locations, replacing the appropriate segments of the original linear features.

Streams also are cut into the terrain surface to improve visualization and attempt to ensure that they flow downhill. Small lakes are eliminated, while the terrain under larger bodies of water is flattened.

Urban areas are populated with basis sets representing typical built-up areas, with generic commercial buildings as well as single family dwelling models and generic street patterns.

"Desert" Data Base

The CCTT "Desert" data base also covers an area which is approximately 100 km by 150 km, located in the southwestern U.S. Its dimensions and organizational structure are nearly identical to the "Central U.S." data base. Its content is similar overall, based on ITD and DFAD features, however because of its location, the feature density is much lower. Vegetation features, in particular, are quite scarce in the source data. SPOT imagery was used as a supplementary data source to obtain "colors" from different areas of the terrain surface, so that the "Desert" data base would have a more realistic appearance. SPOT imagery also is used to support long-range cueing for navigation.

2.2.1 INPUT SOURCES

The CCTT program's terrain data base generation process integrates information from several different types of sources, including:

- DTD sources
- Imagery sources
- Cartographic sources
- Site survey sources.

Each of these is discussed below.

2.2.1.1 DTD Sources

The CCTT primary terrain data bases were created using various NIMA DTD products as the primary sources. The DTD sources used in the CCTT terrain data base generation process include:

- NIMA DTED Level 2
- NIMA ITD
- NIMA DFAD.

Other DTD sources, such as USGS DEMs and DLGs, have been used by E&S to create terrain data bases, but these sources were not specified for use in the construction of the CCTT primary terrain data bases.

NIMA Digital Terrain Elevation Data (DTED)

DTED Level 2 is the source of terrain elevation information for the two CCTT primary terrain data bases. It is used to generate the terrain surface (skin).

NIMA Interim Terrain Data (ITD)

ITD was the primary source of terrain feature information for the two CCTT primary terrain data bases. A significant amount of the terrain feature information used comes from ITD.

Not all of the ITD thematic layers were used in the CCTT terrain data base generation process. The usage of ITD thematic layers can be summarized as follows:

- Surface Configuration/Slope—Not used. Terrain slope is derived from the geometry of the polygonal terrain skin.

- Vegetation—Primary source for vegetation features. ITD built-up area features are deleted and replaced with DFAD areal features representing urban commercial and residential areas. Wetlands, bare ground, brushland, grassland, and forest features are generalized and snapped to the terrain polygons. Cropland and orchard features are each mapped into a single feature type, generalized, and snapped to the terrain polygons.

- Surface Materials—Bare ground features (gravel, sand, silt, clay, peat/organic soils, and evaporites) are mapped to soil type and soil wetness categories. These features, along with any rock outcrop features, are combined with the vegetation layer, generalized, and snapped to the terrain polygons, and a mobility layer is then extracted.

- Surface Drainage—Primary source for rivers and streams, canals, ditches, open water, and other drainage and hydrography features. Linear drainage features are thinned and generalized to retain only major drainage features, standardized to several types and two different widths. Areal drainage features representing rivers and canals are replaced with linear features and assigned a larger standard width. Perennial linear drainage features are further classified relative to fordability based on the water depth average (WDA) and material composition category (MCC) attributes. Small open water features (<1000 m^2) are deleted. The terrain surface underneath larger open water features is flattened, and the features are snapped to the terrain polygons. Islands are deleted. Aqueducts also are deleted, since there are only a few of them present and there is no descriptive attribute information that could be used to depict them in the data base.

- Transportation—Primary source for road, railroad, and airfield features. Roads are mapped to one of four types: 4-lane hard surface roads, 2-lane and single lane hard surface roads, distinguished by road surface type (RST) attribute value, and dirt roads. Dirt roads that do not intersect with a hard surface road, connect to hard surface roads, or extend the end of a hard surface road, are deleted. Cart tracks are thinned. All railroad segments are mapped to a single track railroad type, and spurs are deleted. Areal railroad yards are replaced by corresponding linear railroad segments. All bridge and bridge span features are deleted, since not all logically necessary bridges are included in ITD, and those that are included do not provide orientation information, and may not match the positions of the drainage features which they cross. Instead, bridge models are fabricated to fit each road or railroad intersection with a drainage feature. Ford features are deleted, since the fordable portions of drainage features are determined by their attributes (depth, bottom composition, etc.). Runways are retained as linear features. Other ITD transportation feature types did not occur in the source data.

• Obstacles—Generally not used, with the exception of moat features, representing the flood control canals at Fort Irwin, CA, which are implemented as cuts. Depressions, escarpments, embankments, cuts, and fills are deleted, since they do not correspond well with the terrain elevation data.

Appendix A contains a table summarizing the use of ITD features in the CCTT "Desert" Data Base.

NIMA Digital Feature Analysis Data (DFAD)

DFAD Level 1 , Second Edition, was used as a secondary source of terrain feature information for the CCTT terrain data bases, especially for cultural point features that are not included in ITD, such as towers and buildings. In the urban areas, DFAD areal features were used to define the boundary within which urban basis sets were positioned. In many cases, DFAD features are represented by cluster models, which are composed of multiple individual models, representing agricultural, commercial, government, industrial, public facilities, or residential features.

Appendix A contains a list of the DFAD features used in the CCTT "Desert" Data Base.

2.2.1.2 Imagery Sources

Imagery sources were not used in the creation of the CCTT "Central U.S." Data Base. SPOT imagery was used as a source of terrain color and texture information for the CCTT "Desert" Data Base. SPOT imagery also was used as a background while editing terrain feature information using ARC/INFO.

2.2.1.3 Cartographic Sources

Cartographic sources (i.e., hardcopy maps) were used to identify additional landmarks, typically cultural features not contained in either the ITD or DFAD sources, as well as for reference to cross-check and resolve problems in the content of the DTD sources, and to determine feature thinning criteria. The primary cartographic sources that were used in the CCTT terrain data base generation process were the 1:50,000-scale NIMA TLMs that corresponded to the ITD cells used.

On other terrain data base generation projects, E&S has used either 1:50,000-scale NIMA TLMs, or 1:250,000-scale JOGs as a source for digitizing transportation, drainage, vegetation, and other types of features.

2.2.1.4 Site Survey Sources

A site survey was performed to collect site-specific information for the "Desert" Data Base. Photographs and videos were used as sources for generic, geotypical, and geospecific models and textures. These images were processed using Adobe Photoshop.

2.2.2 OUTPUT PRODUCTS

The set of output products from the CCTT terrain data base generation process include:

- Visual/infrared run-time data bases in ESIG-HD/3000 image generator (IG) format

- Interchange data bases in the SIF and SIF++ (CCTT SIF) formats, which are, in turn, used to produce CCTT SAF, plan view display (PVD), and mobility data bases

- Simulation maps, which are 1:50,000-, 1:100,000-, and 1:250,000-scale hardcopy maps similar to TLMs and JOGs, but reflect the actual contents of the terrain data base.

Each of these types of products is described briefly below.

2.2.2.1 Terrain Data Bases

The CCTT terrain data base generation process produces both run-time data bases for the ESIG-HD/3000 image generator, and data bases in interchange formats, that are then used by other members of the CCTT Integrated Project Team to generate SAF, plan view display (PVD), and mobility data bases.

The ESIG-HD/3000 run-time data bases support both visual and infrared displays. Each polygon in the data base has three sets of viewport-dependent attributes, indicated by bit flags in the run-time data base. These three sets of attributes are used to support visual (Out-the-Window) displays, infrared (IR) displays, and night vision goggle (NVG) displays, respectively. The infrared information is derived solely from the surface material code associated with each polygon. Radar displays also can be supported in this manner.

Data bases also can be output in either the SIF (MIL-STD-1821) or SIF++ interchange formats. SIF++ (also known as CCTT SIF) is an extension of the SIF format, which includes support for cut and fill polygons, multiple model states (e.g. intact, damaged, destroyed), 3-D linear features, and image generator specific information. The CCTT data bases are transmitted to Loral Federal Systems, the CCTT prime contractor, in this form. From this transmittal they, in turn, create run-time data bases to support the other components of the CCTT simulators. To support the CCTT SAF component, a run-time SAF data base is created, that includes the 3-D models used for intersections, bridges, overpasses, etc., 3-D road vectors, and road polygons. To support the plan view displays used on various CCTT workstations, a run-time PVD data base is created. To support the motion bases of the CCTT manned modules (i.e., the simulators themselves), a run-time mobility data base is created. Note, that from the point of view of the terrain data base developers, the creation of these other run-time data bases is not considered to be part of the CCTT terrain data base generation process, and the software tools used to create these data bases are not considered to be a part of the CCTT terrain data base generation system.

2.2.2.2 SIMULATION MAPS

Simulation map data is extracted from the EaSIEST internal data base using the EaSIEST Data Extraction Tool (DET), and is imported into ARC/INFO where simulation maps are generated using the same software used by TEC DPC.

2.2.3 PROCESS

As shown in Figure 10, the CCTT terrain data base generation process consists of three major phases:

1. Data Base Design, in which the initial structure and organization of the data bases are determined, source data is obtained, and, for the "Desert" Data Base, a site survey is conducted and SPOT imagery is processed

2. Data Processing and Integration, in which the terrain skin is created and optimized, vector feature data is processed, 3-D models are created, and then these components are integrated

3. Data Base Formatting, in which image generator run-time data bases, interchange data bases, and simulation maps are created, and testing is performed.

The first phase is concerned with preliminary activities. The second phase is concerned with processing and integrating the various source components, including the terrain skin, features, and 3-D models. The third phase is concerned with generating the various products of the process, and with testing. These phases are not completely sequential. Each of these phases is discussed in more detail in the following subsections.

2.2.3.1 Data Base Design

This phase consists of preliminary activities performed before the actual terrain data base generation process. These activities include:

• Creating DB Design, in which the overall structure and organization of the data bases was defined, based on the requirements and priorities of the CCTT program, as specified by the CCTT contract statement of work (SOW)

• Obtaining Source Data, in which the Government Furnished Equipment (GFE) source DTED, DFAD, and ITD data, and the corresponding hardcopy maps, were obtained, as well as source data for moving 3-D models, including photos, videos, and engineering drawings

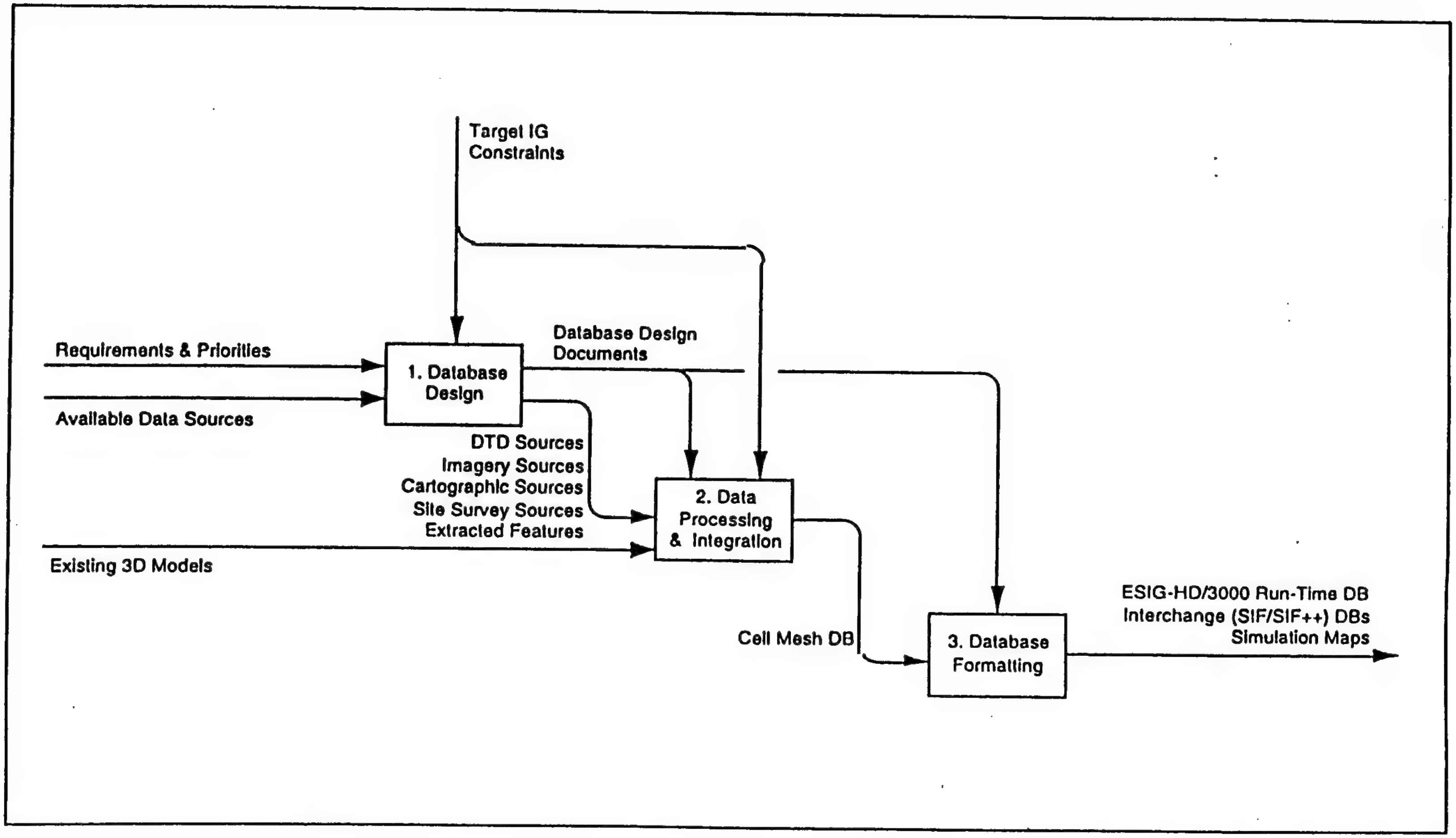

Figure 10. CCTT Terrain DB Generation Process

• Conducting Site Survey (for the "Desert" data base only), in which terrain data base generation personnel visited the National Training Center (NTC) Fort Irwin, CA; Twentynine Palms, CA; Fort Knox, KY; Fort Benning, GA; Fort Sill, OK; and Fort Leonard Wood, MO; to collect information on landmarks and other significant features

• Processing SPOT Imagery (for the "Desert" Data Base only), in which SPOT imagery was orthorectified using the corresponding DTED and the Socet Set image processing tools, cleaned-up using Adobe Photoshop to remove clouds, etc., Gouraud shaded in mountain areas to enhance their appearance, quantized, imported into ARC/INFO, and used to extract area features of different colors, with higher elevations generally corresponding to darker colors, to enhance the visual appearance of the "Desert" Data Base.

The relationships among these activities, and their inputs and outputs, are shown in Figure 11.

2.2.3.2 Data Processing and Integration

This phase involves the creation and optimization of the terrain surface, the preprocessing of feature data in vector form, the construction of both generic and specific 3-D models, and the integration of these components. The activities that make up this phase include:

• Creating Terrain Skin, in which the initial terrain skin is created and then optimized, based on local terrain roughness metrics, using the EaSIEST Terrain Modeling System. This consists of the following steps:

— Reading the DTED source data from magnetic tape or CD-ROM, and creating corresponding disk files

— Projecting the terrain surface from geographic coordinates to local Cartesian coordinates, and resampling the elevation post grid at a specified spacing (i.e., 30m)

— Creating a constraint file containing a set of terrain optimization tables, where each table entry consists of an optimization threshold value, and a range of slope values, as calculated from the polygonal terrain skin, in which that threshold is to be applied

— Creating and optimizing the terrain skin, consisting of triangular facets, using the optimization tables contained in the constraint file, as described:

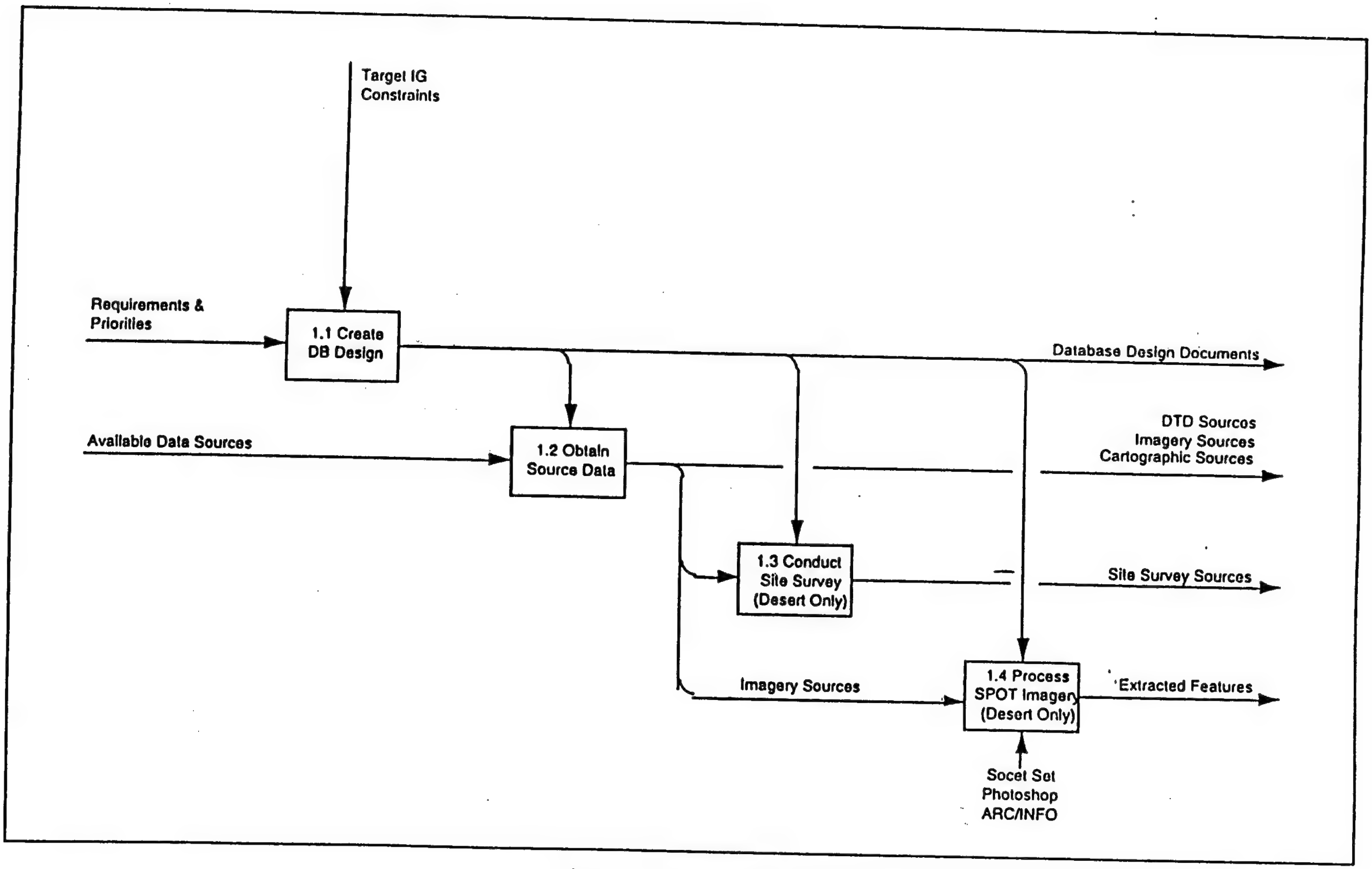

Figure 11. Data Base Design

• Processing Features, in which feature data is imported and/or digitized, feature and attribute codes are translated to EaSIEST codes, and features are thinned, generalized, and edited, using the EaSIEST Terrain Decoration System and ARC/INFO. This consists of the following steps:

— Reading the ITD and/or DFAD source data from magnetic tape, and creating corresponding disk files

— Converting the feature to the internal EaSIEST format, including the translation of feature codes and attribute values to EaSIEST internal Evans & Sutherland Identifier (ESids)

— If necessary, digitizing additional features from hardcopy sources, using either ARC/INFO or an EaSIEST digitizing tool

— Deleting, thinning, generalizing, and editing the features in each thematic layer, using ARC/INFO and/or an EaSIEST thinning tool, as described below:

• Creating 3-D Models, in which generic, specific, and moving models are all created, using the EaSIEST Feature Modeling Tools

• Integrating Terrain Skin and Features, in which the terrain skin and the features are integrated, using the EaSIEST Decorated Terrain Processor, including cut and fill, and the placement of intersections, overpasses, bridges, and cultural point features with either custom 3-D models, generic 3-D models, or cluster models.

The relationships among these activities, and their inputs and outputs, are shown in Figure 12.

The terrain skin optimization process begins with a homogeneous grid of 30 m right triangular facets, and then iteratively replaces groups of eight adjacent triangular facets of equal size (four pairs), covering a square area, with a single pair of larger triangular facets. This is based on an evaluation of the distance that the terrain skin surface will be moved by this operation at five different points: the center of the eight-facet group, and the midpoint of each of its four edges. If these distances are all less than the threshold specified in the optimization table, then the replacement is carried out, and the corresponding edge midpoints of adjacent facets are adjusted to match.

Each optimization table entry specifies an optimization threshold distance and a range of slope values where that threshold is to be applied. This allows the optimization thresholds to be made more sensitive to the local slope, so that smaller thresholds can be used in flatter areas to retain small variations in the terrain surface, while larger threshold values are used in rougher areas. The appropriate optimization table entry to be used in each case is determined by the minimum of the slopes at each of the five points identified above. The slope at each of these points is the average of the slopes of the six surrounding facets.

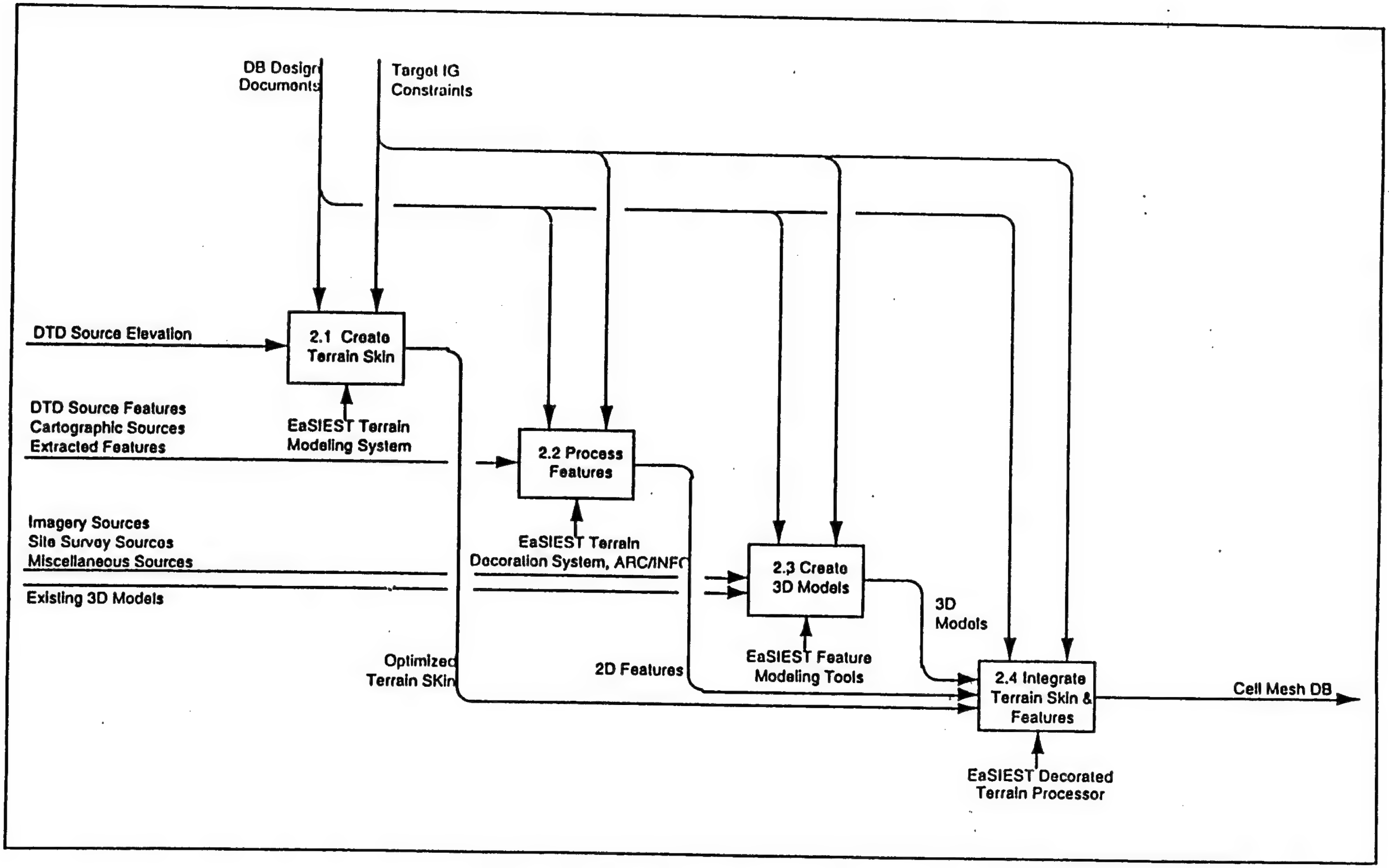

Figure 12. Data Processing and Integration

There may be multiple optimization tables, designed to be applied in modules with different terrain roughness characteristics, based on two measurements: Sigma-T, which is based on the standard deviation of the elevation post values within a module, with small values indicating flat terrain, and large values indicating large differences in elevation; and Roughness Factor, which is based on the differences between adjacent elevation posts. Separate optimization tables are created corresponding to different ranges of these two metrics, representing different terrain types. Thus, the Sigma-T and Roughness Factor of the current module determine which optimization table is used, while the local slope determines which entry in that table is used.

When the orientation of all of the triangular facets in the terrain skin is in the same direction (e.g. diagonals running from southwest to northeast), physiographic features, such as ridges, valleys, and river banks, which run in the opposite direction, are not adequately represented. The elevation at the center of each facet pair is used to select the orientation of the facets. The center point of each of the two possible diagonals is compared with the center point elevation, and the closest diagonal is used. The result of the terrain skin creation and optimization is a collection of abstract terrain skin files.

Feature processing consists of a number of operations, including feature elimination, thinning, generalizing, editing, and translation. Many features are eliminated from the original source inputs, primarily to reduce the feature density, and therefore, the polygon density, of the resulting data base. Features of little importance to the training situations addressed by the CCTT program, such as islands, and walls/fences in the "Desert" data bases (which are assumed to represent chain-link fences), are eliminated. Features which are clearly inaccurate, and would cause anomalies in the data base, also may be deleted if this is the most effective method of correcting the problem. Features below specified size thresholds are typically eliminated. For example, all lakes and forested areas with areas less than 1000 m^2 are deleted. Isolated, disconnected, or dead-end cart tracks and roads, odd connecting roads and ramps, and loops in road and drainage features are eliminated. Road segments overlaying urban areas, except for through roads and area drainage features are deleted.

Features are thinned and/or generalized to meet the constraints of the image generator. In dense areas, individual features are thinned to reduce the overall feature density. In the "Central U.S." data base it was discovered that ITD transportation features were captured such that major roads came before less significant roads. By finding the transition point marking the last major road, this characteristic of the source data was used to eliminate all minor roads. Unfortunately, this method could not be applied to the "Desert" Data Base, as the features in those ITD cells were not ordered in this manner. Thus, the "Desert" Data Base transportation network had to be manually thinned, as did the drainage networks for both data bases. Fortunately, the relatively low feature density of the "Desert" Data Base required very little manual editing to be performed. Linear features such as roads are generalized, then spline fit and resampled to eliminate sharp angles, thus producing more "realistic-looking" shapes.

Editing is performed to correct inconsistencies or other types of inaccuracies, such as road segments, that do not quite meet. Significant manual editing was required to correct inconsistencies in road attributes and classification across ITD cell boundaries.

During conversion from DTD source formats to EaSIEST internal feature format, feature code mapping and attribute standardization are used to simplify the contents of the data base. For example, all types of railroad features are mapped to single track railroads. The widths of all linear features are standardized. The widths of drainage features are standardized to two different values: a smaller width for streams and narrow rivers represented by linear features, and a larger width for wide rivers represented by areal features, which are replaced with linear features. Small segments within linear features are merged. The connecting of roads at intersections was a CCTT requirement that was new for an EaSIEST visual simulation data base.

Urban area features from DFAD were combined with the ITD vegetation coverage. ESids for area features were mapped based on the vegetation type, material type, and soil wetness. Vegetation and surface material area features were snapped to terrain facet edges to reduce the number of polygons and create more basis sets, and to accommodate the SAF limitation on multiple terrain types within a facet. Several types of conflicts were eliminated by altering the ESids of area features. For example, all forest and open water facets containing roads were changed to grassland. Urban facets with a slope of more than 15 degrees were changed to grassland. Open water facets with a slope greater than 1 degree were changed to forest. Point features were removed from open water facets, urban area facets, and facets containing mixed feature coverages. The result of feature processing is a collection of vectorized feature data files.

Many types of cultural point features are represented by 3-D models. These include agricultural features (i.e., farms), airfields, buildings, commercial and industrial facilities, storage facilities, powerline and communication towers, Government and military installations, schools, churches, hospitals, and residential areas. Generic 3-D models are created to represent these features. DFAD Feature Identification (FID) codes are mapped into ESids. Often, these features consist of a cluster of models. For example, a farm might consist of a house, a barn, and a silo. For variety, multiple versions of these generic cluster models may be created. Also, most of the DFAD-based 3-D models in the CCTT Data Bases can be damaged or destroyed, thus, include variants representing each of these states. Finally, models may be used to create basis sets. A basis set is a generic model which can be used to replace any terrain facet with the appropriate size, orientation, and a single feature type, such as forest, farmland, or built-up area. Multiple versions of each basis set are typically constructed and selected randomly to reduce the unnatural repetitive visual effects that can otherwise occur.

The integration of the features with the terrain skin is a multistep process supported by the Decorated Terrain Processor (DTP). DTP expands vector linear features (e.g. roads) into polygons, and determines the height of features relative to the terrain surface. First junctions and intersections of linear features are automatically identified and classified. Road intersections and overpasses are assigned different ESids from bridges. The linear features are cut back from these

points, and custom 3-D models are constructed to match the intersection geometry. A second pass integrates the linear features into the terrain surface using a cut and fill technique. Rules specifying the maximum permitted slope for each type of linear feature are used to assign relative heights to each vertex. Negative relative heights indicate where the feature must be cut into the terrain, while positive relative heights indicate where the terrain must be built up to support the feature. Lateral slope is taken into account so that roads on the side of a hill are cut on one side, while being filled on the other. Absolute heights also may be assigned to linear or point feature vertices. The shoulders of both cuts and fills are variable with the shoulder width specified as a percentage of the feature width. For the "Central U.S." data base, a 20 percent - 60 percent - 20 percent split was found to work well for roads, while for the "Desert" data base, a 30 percent - 40 percent - 30 percent split was found to work well for wadies. Cuts break the terrain skin facets into multiple polygons, while fills are built on top of the terrain skin. This pass also applies area features to the terrain skin facets, and positions 3-D models to represent point features. Intersection models are placed at road and railroad junctions. Overpass models are placed where transportation features cross but do not meet. These must be specifically identified, indicating which feature crosses over the top of the other. Overpass models have multiple versions that correspond to intact, damaged, and destroyed states.

Bridge models are placed where transportation features cross drainage features. Customer time and cost constraints and requirements determine whether specific or generic parameterized models are used for bridges. All bridges are custom-built to align with, and connect to, specific road segments. One of several generic bridge model types is selected by length and the type of the crossing feature (road or railroad). Bridge models also have multiple variants that correspond to intact, damaged, and destroyed states.

Tunnels, raised roads, trestles, etc., still cause a number of problems. ITD tunnel features are used to locate the approximate endpoints of tunnels, and the terrain at those locations is examined to determine if it is suitable for a tunnel portal. If so, the road or railroad segments corresponding to the tunnel are marked as being a tunnel. Transportation feature codes can be marked as "tunnel capable" under specified conditions (depth of cut, etc.). If the depth of a cut exceeds the specified threshold for one of these features, a tunnel is automatically created.

2.2.3.3 Data Base Formatting

This phase involves the creation of the run-time image generator data base, the creation of the interchange format data base(s) which are in turn used to create the SAF, PVD, and mobility data bases, and the production of the simulation maps. It also covers testing. The activities that make up this phase include:

- Formatting IG Data Base, in which the run-time visual data base for the ESIG-HD/3000 image generator is created—infrared and night vision displays are supported by the same data base, using different sets of colors and/or texture maps, based on the material codes from the polygons

• Performing Testing, in which the run-time data base is checked both analytically, relative to the consistency of its internal structure and whether it is within the parcel polygon budget, and visually, using both 2-D plots and the image generator

• Formatting Interchange Data Bases, in which interchange formats in both SIF & SIF++ (CCTT SIF) formats are created, including all 3-D models, polygons, and vector features

• Producing Simulation Maps, in which feature data is extracted from the EaSIEST data base using the Data Extraction Tool and imported by ARC/INFO, where it is used to create plots and color separates which are used to print 1:50,000-, 1:100,000-, and 1:250,000-scale maps of the simulation data base, using the format of a 1:50,000-scale TLM.

The relationships among these activities, and their inputs and outputs, are shown in Figure 13.

Because of the automated nature of much of the data base generation processing, many problems are not found until a partial image generator data base is output. Also, as preliminary versions of portions of the data base are released to users for field testing, significant amounts of feedback are received on the visual aspects of the data base (since any visual anomalies that are present can be seen), but relatively little feedback is provided on the less obvious aspects of the data base, such as its training effectiveness.

2.2.4 TOOLS

The principal tools used in the CCTT terrain data base generation process include:

• The SOCET (pronounced "socket") set tools, developed by GDE, and are used to orthorectify SPOT imagery using DTED, for the "Desert" Data Base

• Adobe Photoshop, a commercial off-the-shelf image processing and manipulation tool, used for SPOT and photo/video image processing, to create textures that are applied to terrain features and moving models

• The EaSIEST tool set, developed by E&S, which is used for terrain elevation and feature data processing and integration, and consists of the following components:

— Feature Modeling Tools - used to create 3-D models, both static (e.g. buildings) and dynamic (e.g. vehicles)

— Terrain Modeling Tools - used to create the terrain skin and features, and consisting of:

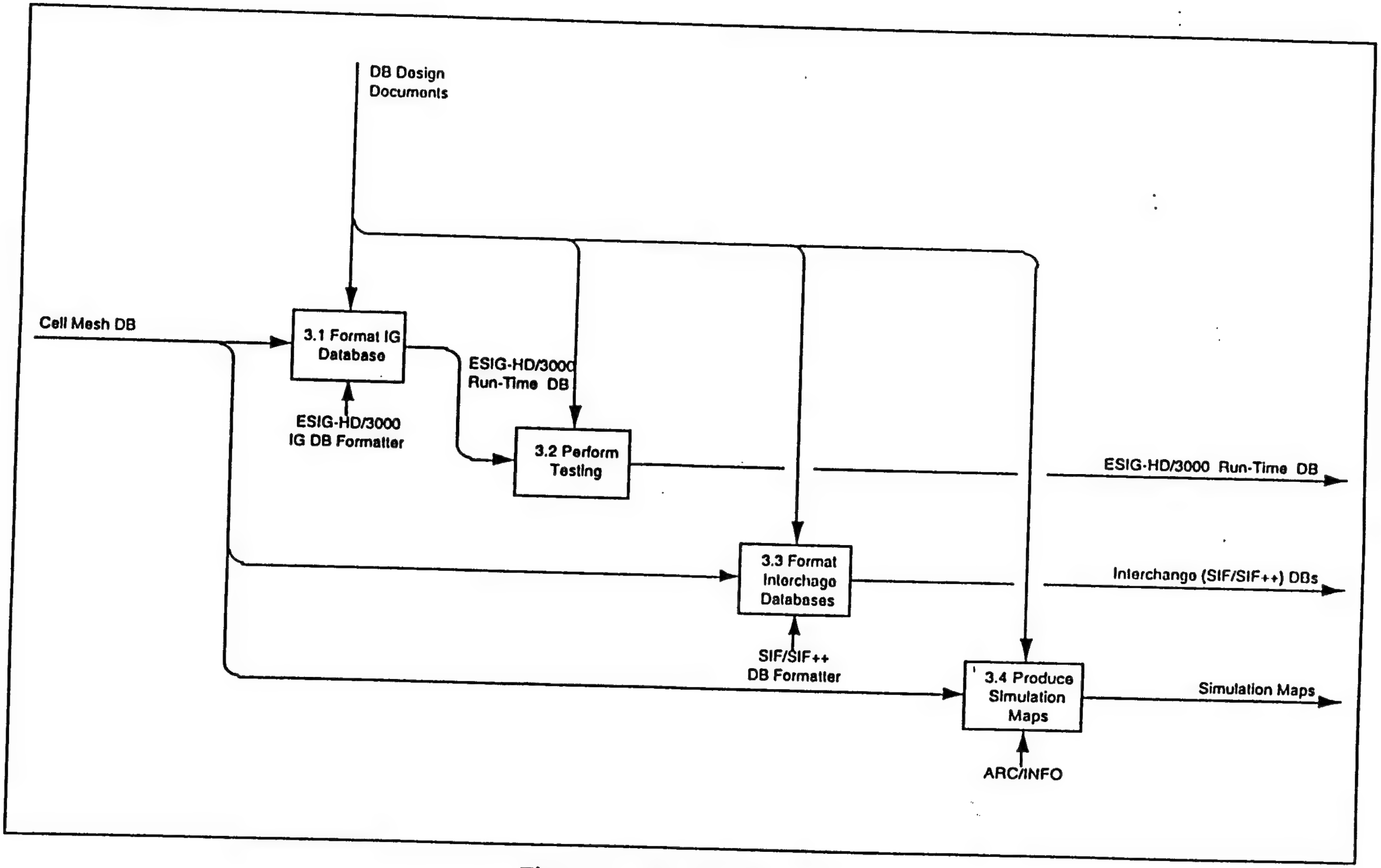

Figure 13. Data Base Formatting

— Terrain Modeling System (TMS)—used to create the terrain skin, including loading DTED from tape or CD into disk files, projecting to Cartesian coordinates and resampling the terrain grid, creating terrain skins for individual modules, and creating the constraint files which control these processes, containing the data base parameters, origin, facet size, optimization tables, etc.

— Terrain Decoration System (TDS)—used to create the terrain features, including loading DFAD and ITD from tapes onto disk files, conversion to Cartesian coordinates, thinning features, using an in-house algorithm, and digitizing and/or editing features

— Decorated Terrain Processor (DTP)—used to integrate the terrain skin and features, converting features into polygons, replacing intersections, overpasses, bridges, and similar features with 3-D models, and adjusting roads, railroads, and rivers using cut and fill techniques

• DET—which is used to extract data from the internal EaSIEST data base, and exports that data to ARC/INFO for simulation map creation

• The ESIG-HD/3000 IG Formatter—which is used to create the run-time data base format used by the ESIG-HD/3000 image generator

• The SIF/SIF++ Formatter(s)—which are used to create interchange data bases in either SIF or SIF++ (CCTT SIF) formats

• The ARC/INFO commercial GIS for feature data editing and simulation map creation.

The relationships among these tools, and how they fit into the data base generation process, is shown in Figure 14.

2.2.5 MANAGEMENT

The generation of the CCTT primary terrain data bases has been a unique activity, using a custom developed process to address the unique requirements of the CCTT program. It is difficult to measure the time required to create the "Central U.S." Data Base, since the precise start time for this activity was not well defined. Also, there have been many changes in requirements, and therefore in the terrain data base generation process, during the course of the activity.

Up to 15 people have been involved in the terrain data base generation process, with the majority of these involved in the development of specific and/or generic 3-D models.

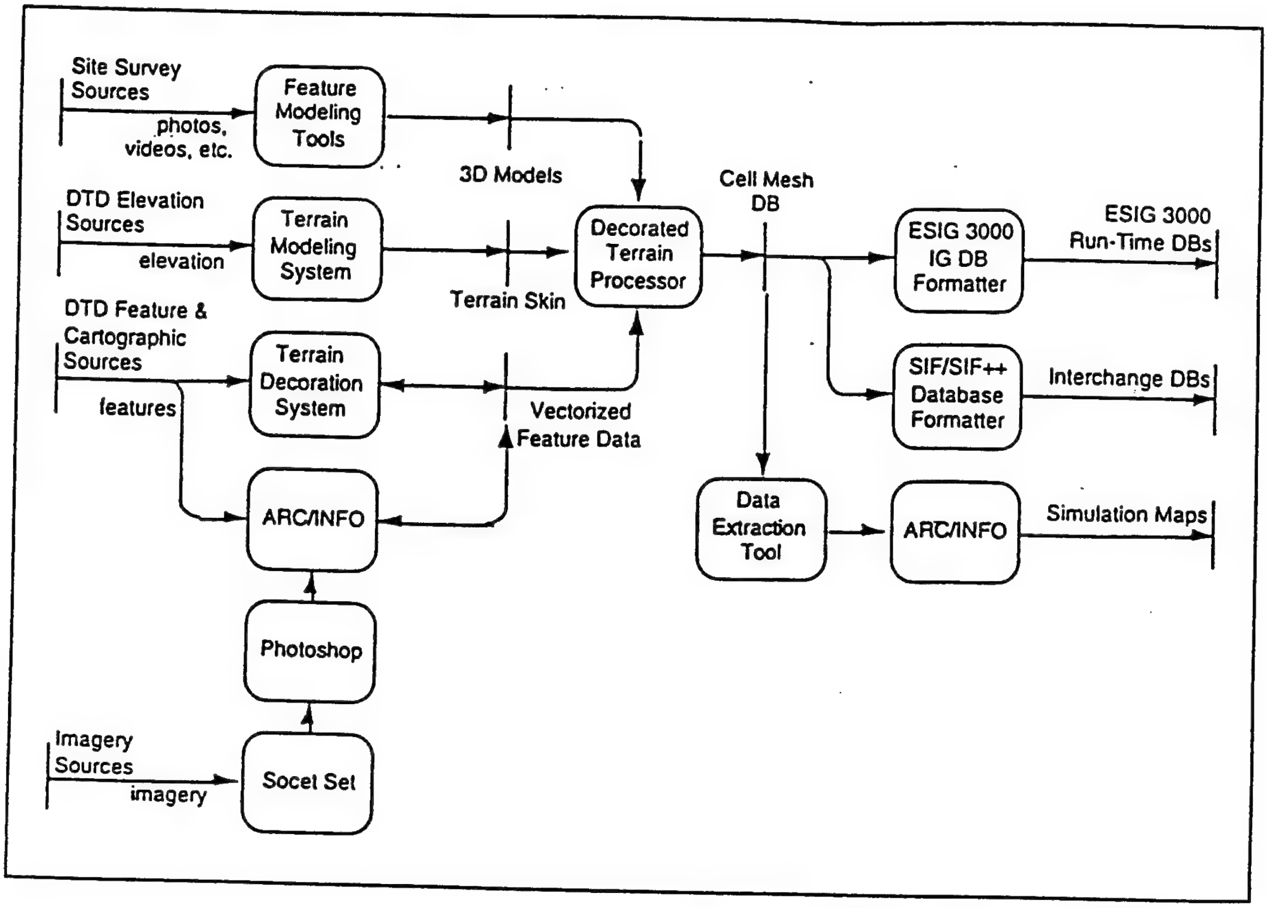

Figure 14. CCTT Terrain DBGS Data Flows

In general, the modules that make up a CCTT terrain data base can be processed in parallel. Initially, a collection of typical modules is selected, characterizing each of the types of terrain found within the data base coverage area, and used to develop the various rules and parameters that control the various processing stages. These rules and parameters are iteratively modified and the sample modules are reprocessed until the desired results are achieved. The remaining modules are then put into production, using the same rules and parameters. If problems are discovered in a particular module, its content is edited and/or its rules and parameters are modified, and it is reprocessed.

2.2.6 PROBLEMS & ISSUES

The most significant problems and issues related to DTD products that were identified by the personnel who performed the generation of the CCTT primary terrain data bases are:

1. The lack of an integrated source of terrain elevation and feature data requires a great deal of work to be performed to integrate these two primary types of source data. Much of the complexity of the CCTT terrain data bases is associated with the cutting and filling of roads, railroads, and streams

2. The lack of explicit feature relationship information at locations such as road intersections, overpasses, bridges, etc., makes it very difficult to properly construct these features in an automated manner. It is necessary to know which features pass over and under at bridges and overpasses, and what the connectivity is between the features that meet at nodes. This is currently handled using a combination of generic rules (e.g. roads always go over streams), and other sources (e.g. analysis of imagery and/or site surveys to determine what road junctions and overpasses actually look like)

3. The lack of detailed traceability or lineage information (i.e., metadata) back to the real world makes it impossible to accurately determine the fidelity of the resulting synthetic environment terrain data base

4. The ITD datasets used contained a number of different types of inconsistencies and errors that had to be manually corrected, including:

— Inconsistencies across cell boundaries, particularly relative to the attributes of highway features

— Isolated road and cart track segments

— Odd connectors between transportation features, perhaps representing access ramps or other similar structures

— Small loops in transportation and surface drainage features

— Sequencing of power line towers, particularly when multiple features overlap

— Complex intersections of linear features

— Curves and angles in transportation features

— Other interactions between transportation and drainage features, such as a road passing over a dam with a spillway.

5. Thinning transportation and drainage networks was very difficult because it was not possible to automatically distinguish major roads and rivers from minor ones. Because of inconsistencies in the attribution of roads, attempts to classify them using attributes such as width, surface characteristics, divided vs. nondivided, and weather type were not successful. It was finally discovered that for the "Central U.S." data base, road segments were ordered in the Transportation coverage such that the major roads were first in the file, and it was possible to discover the "magic number" where minor road segments began in the dataset, and to filter out all segments with higher identifiers. This approach was not successful for the Transportation coverage of the "Desert" Data Base, nor was it successful for surface drainage features in either data base

6. The presence of topology information in new NIMA DTD products will be very useful, but will impact the existing EaSIEST software significantly, as topological relationships are not currently taken into account in the operations that the EaSIEST software performs

7. Though ARC/INFO is used to support EaSIEST, primarily for editing feature data and to correct problems, it is not designed specifically for visual simulation, but has proven to be an effective tool for DTD manipulation.

2.3 MTSS TERRAIN DBGS

The MTSS supports the USAF 58th Training Support Squadron (58th TRSS), which is part of the 58th SOW, based at Kirtland Air Force Base, Albuquerque, NM. The MTSS is operated by a contracting team led by Lockheed Martin, with support from Loral Defense Systems—Akron, and Hughes Training, Inc. The MTSS supports search and rescue (SAR) and special operations helicopter and C-130 training and mission rehearsal. It operates the largest DoD terrain data base generation system, the collocated Simulator Data Base Facility (SDBF), and a network of simulators, including a TH-53A Operational Flight Trainer (OFT), an MH-53J Weapon System Trainer (WST) and Mission Rehearsal System (MRS), an HH-60G OFT, an MH-60G WST, and an HC-13OP WST, as well as networked electronic classrooms and a network observation center from which all simulators may be monitored. An MC-130H Weapon System Trainer is scheduled to be added early in 1996.

The MTSS terrain data base generation system has developed more than 1.6 million square nmi of correlated visual and sensor data bases, including a data base covering a large portion of the southwestern U.S. These are geospecific data bases developed to support a helicopter pilot's point of view, which may be as low as 50 feet. Therefore it is primarily concerned with potential helicopter landing areas, and with features and attributes relevant to helicopters, such as towers and poles, vegetation, etc. The data bases support correlated visual, infrared (FLIR and NVG), and multimode radar simulations. The data bases are constructed primarily from 1:250,000-scale DTD sources: DTED Level 1 for elevation data and DFAD Level 1 for feature data, with small areas of enhanced detail (target areas, etc.) filled-in using high resolution imagery to replace the DFAD, and geospecific 3-D models. Coarser data also can be automatically produced, consisting only of generic textures based on DFAD area features.

The data bases are organized into 1 degree by 1 degree cells, divided into 15 rows by 15 columns arrays of 4 min. by 4 min. blocks. Each physical data base file covers a 1 degree by 12 degree area, and contains references to 3-D model libraries and texture images. The Southwest U.S. data base consists of 61 1 degree by 1 degree cells.

2.3.1 INPUT SOURCES

The MTSS terrain data base generation process integrates information from several different types of sources, including:

- DTD sources
- Imagery sources
- Cartographic sources.

Each of these is discussed below.

2.3.1.1 DTD Sources

The MTSS terrain DBGS creates terrain data bases using standard NIMA DTD products as its primary data sources. The DTD sources used in the MTSS terrain data base generation process include:

- NIMA DTED Levels 1 , 2, and 3
- NIMA DFAD Levels 1, 1C, 2, and 3C
- Standard Simulator Data Base (SSDB) Interchange Format (SIF).

The use of ITD has been examined, however to date there has not been enough ITD available to justify developing an ITD import capability. Also, ITD is missing some features, such as power lines, which are critical to helicopter training and mission rehearsal.

NIMA Digital Terrain Elevation Data (DTED)

DTED is the primary source of terrain elevation data used by the MTSS terrain data base generation system. When DTED is not available, the only alternatives are to digitize contour lines from cartographic sources or to extract elevation data from stereo imagery.

NIMA Digital Feature Analysis Data (DFAD)

DFAD (Level 1) is the primary source of terrain feature information used by the MTSS terrain data base generation system, except in high resolution areas, where features are digitized from imagery sources.

In general, all area and linear features are used to create surface color. All DFAD attributes are retained to support the output of feature data in DFAD format, although some, including FAC codes, height, length, and width, are not used because of their generic nature. For example, the height of the models used for point features are not derived from the DFAD feature heights. Forests are represented by textured ground polygons with scattered generic tree models, rather than as canopies.

Standard Simulator Data Base (SSDB) Interchange Format (SIF)

Existing flight simulator data bases in SIF format can be used as an alternative source of terrain elevation data, terrain feature data, imagery, and 3-D models.

2.3.1.2 Imagery Sources

Imagery is used to enhance specific high resolution areas. Typically, the DFAD features are removed from the high resolution area, and are replaced with features digitized from the imagery, while the imagery also provides geospecific ground texture. All types of imagery can be used, either digital or hardcopy. Hardcopy imagery is first scanned, then controlled through warping or orthorectification. Digital imagery saves time, and orthorectified digital imagery is best. Heads-up digitizing is used to extract features from the imagery.

Stereo imagery has not yet been used, but a beta version of Training and Rehearsal Generation Toolkit (TARGET) stereo extraction software is available.

The primary types of imagery sources used, in order of preference, are:

- National imagery, in NITF format
- SPOT imagery
- Airborne imagery
- Handheld photos and/or videos.

The worst case is paper hardcopy with writing or grids superimposed on the imagery.

A controlled imagery product, such as CIB, would be preferable to DFAD for most area coverage, but would not necessarily support infrared and radar data bases adequately. Also, there are limitations in the current image generators that would make CIB difficult to use, as these systems were designed to use generic textures, rather than geospecific imagery texture:

- The CompuScene V has a texture capability of 240 on-line 512 by 512 monochrome texture maps, with up to 262,000 texture maps available through texture paging

- The CompuScene VI adds color to CompuScene V capabilities

- The PT-2000 IGs have no imagery texture capabilities (40 256 by 256 color texture maps, 80-160 with additional memory, with no texture paging).

2.3.1.3 Cartographic Sources

Cartographic sources (i.e., hardcopy maps) are used when imagery and/or DFAD is not available. The primary type of cartographic source that is used is the 1:250,000-scale JOG, but all types and scales of cartographic sources can and have been used. Scanning and heads-up digitizing are used to extract features from cartographic sources. Elevation data has been produced by digitizing contour lines from JOGs in a semi-automatic process, but this requires approximately 1,000 times the level of effort required using DTED.

2.3.2 OUTPUT PRODUCTS

The output products from the MTSS terrain data base generation process include:

- Visual and infrared run-time data bases in all Lockheed Martin image generator (IG) formats

- Visual simulation data bases for MH-53J, MH-60G, and C-130 radar simulators

- Radar run-time data bases for MH-53J, MH-60G, and C130 radar simulators

- Gridded elevation data in standard DMA DTED format

- Vector feature data in standard DMA DFAD format

- Interchange databases in the SSDB SIF

Each of these types of products is described briefly below.

The primary outputs produced by the MTSS terrain data base generation process are the run-time data bases that support several different Lockheed Martin image generators. These include:

- CompuScene V image generator run-time data bases, which support the TH-53A Operational Flight Trainer, MH-53J WST, MH-60G WST/MRS, and HC-130P WST simulators

- PT-2000 imager generator run-time data bases, which support the HH-60G OFT

- SE-2000 image generator run-time data bases, which support the MH-53J Aerial Gunner and Scanner Simulator (AGSS).

In addition, MultiGen® OpenFlight™ data bases can be output to support the MH-53J Part Task Trainer. This system currently uses an SGI Onyx. MultiGen® OpenFlight™ data bases are used in conjunction with Paradigm Simulation's Vega software on SGI workstations.

The MTSS has just begun to use ModSAF to provide ground threats and additional friendly forces. Currently, this capability is limited to using the existing ModSAF CTDB format data bases, which are very small for helicopters and aircraft. A limited capability to generate CTDB data bases internally has recently been added.

An ESIG-4000 image generator is scheduled to arrive in February 1996 to support an MC-130H (COMBAT TALON) simulator. A copy of the EaSIEST software will be available to support this system. Data from the TARGET internal data base will be exported to EaSIEST in using SIF format.

The run-time visual data bases are used to support infrared (FLIR) sensor displays, using a different color look-up table. The infrared software model also takes location, time of day, temperature, and other environmental factors into account.

The radar data bases are more diverse, with different resolutions reflecting the differences in the different types of radars being modeled. The different types of radars also produce different types of displays. A terrain-following/terrain-avoidance (TF/TA) radar shows blobs representing terrain at the current altitude, while a precision ground mapping radar shows a view created using cultural features and 3-D models. Also:

- The MH-53J and MH-60G radar data bases are created using information extracted directly from the TARGET internal data base

- The C-130 radar data base needs some data not provided by the TARGET data base, and is produced in a more indirect manner, from DFAD format output, as described below.

DTED and DFAD also are optional outputs of the MTSS terrain data base generation process. Most fields in the DFAD output are filled in, and many attributes are carried through the TARGET internal data base solely for this purpose. Some features are not supported by NIMA DFAD, as extended FID codes are used in the TARGET data base.

Finally, data bases in the SSDB SIF, as defined in MIL-STD-1821, may be created, containing gridded elevation data or polygonized terrain, 2-D and 3-D vector feature data, 3-D models, and texture. These data bases are archived by the collocated SDBF for use by other DoD programs.

2.3.3 PROCESS

As shown in Figure 15, the MTSS terrain data base generation process consists of five major phases:

1. Data Base Specification, in which the requirements for a data base are identified, a data base specification is created, and source data is acquired and analyzed

2. Data Base Generation, in which the source data is processed and the data base is produced

3. Data Base Formatting, in which the run-time image generator and radar data bases are formatted, and NIMA, SIF, and other outputs are created

4. Testing, in which internal Quality Assurance (QA) and Configuration Management (CM) procedures, customer reviews, and formal acceptance testing are carried out

5. Data Base Maintenance, included as a separate part of the MTSS contract, in which data base updates and error correction are performed.

The first phase is concerned with preliminary activities. The second phase is concerned with processing and integrating the various source components, including the terrain elevation data, features, 3-D models, and texture. The third phase is concerned with generating the various products of the process. The fourth phase deals with testing, quality assurance, and configuration management, while the final phase deals with maintenance. These phases are not completely sequential. Each of these phases is discussed in more detail in the following subsections.

In "surge" mode, the entire process is very compressed, with everything being done in parallel to the greatest extent possible. There is a customer review on the third day, when the data base is 80-90 percent complete, but formal quality assurance and configuration management are put off until later. This compressed process is driven by the date on which aircrews are to arrive and begin training. The success of this compressed process is highly dependent on the availability of DTED and DFAD.

2.3.3.1 Data Base Specification

This phase consists of preliminary activities performed before the actual terrain data base generation process. These activities include:

- Identifying Requirements, in which the basic requirements of the data base, including its location and size, and the number and locations of enhanced high resolution areas, are identified

- Creating data base Specification, in which design specifications for the data base are created

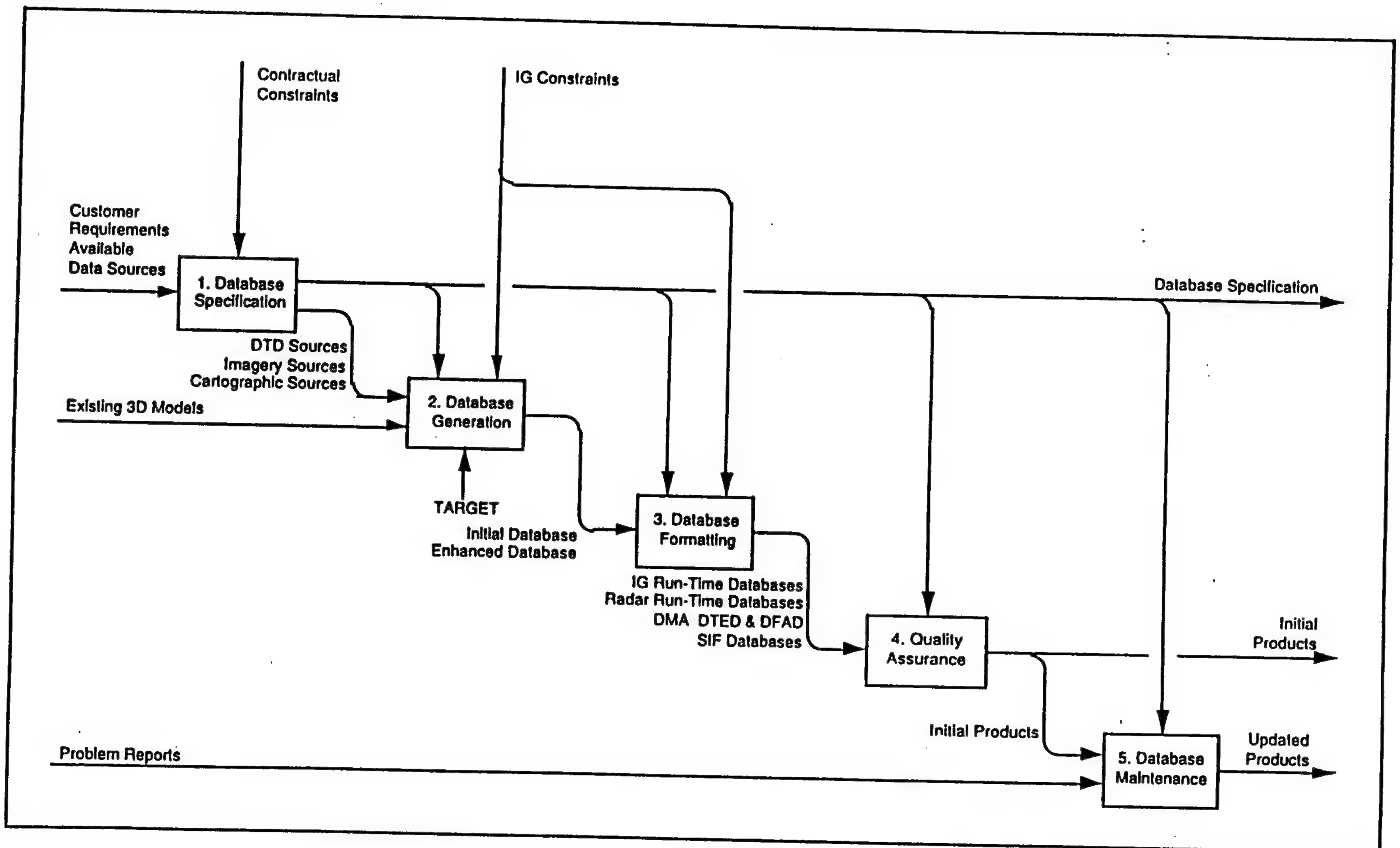

Figure 15. MTSS Terrain DB Generation Process

• Acquiring Source Data, in which all available DTD sources, imagery sources, and cartographic sources for the data base coverage area are obtained

• Analyzing Source Data, in which the available data sources are evaluated to identify their usability, as well as any key vertical obstructions and/or geospecific models in the imagery for the enhanced high resolution areas.

The relationships among these activities, and their inputs and outputs, are shown in Figure 16.

2.3.3.2 Data Base Generation

This phase involves the processing of DTD elevation data in matrix form, DTD feature data in vector form, imagery in raster form, the construction of 3-D models from imagery, and the integration of all of these elements. The activities that make up this phase include:

• Processing Terrain Elevation Data, in which NIMA DTED is read from magnetic tape or CD-ROM into blocked (1" by 1") terrain data files, checked to remove spikes and other artifacts, edge matched, cleaned up along coastlines and other large bodies of water, and triangulated to create a TIN representation

• Processing Cultural Feature Data, in which NIMA DFAD is read from magnetic tape into blocked (1 " by 1 ") culture files, filtered, thinned, if required, and edited

• Processing Imagery Data, in which imagery and hardcopy cartographic sources are scanned, controlled, and resampled

• Building 3-D Models, in which geospecific models are created from imagery or other sources

• Merging Terrain and Culture, in which 2-D features are combined with the TIN, and generic models, such as trees, cacti, and buildings, are "scattered" over specified areas within the data base

• Enhancing High Resolution Areas, in which, for the specified high resolution areas, DFAD background area features are replaced with imagery, features are digitized from the imagery sources to replace and augment the DFAD features, and geospecific 3-D models are added.

The relationships among these activities, and their inputs and outputs, are shown in Figure 17.

After initial processing and cleanup, the terrain elevation data for each 1 in. by 1 in. block is converted into a TIN representation. The TINning algorithm used is incremental and additive, with multiple stopping criteria which include:

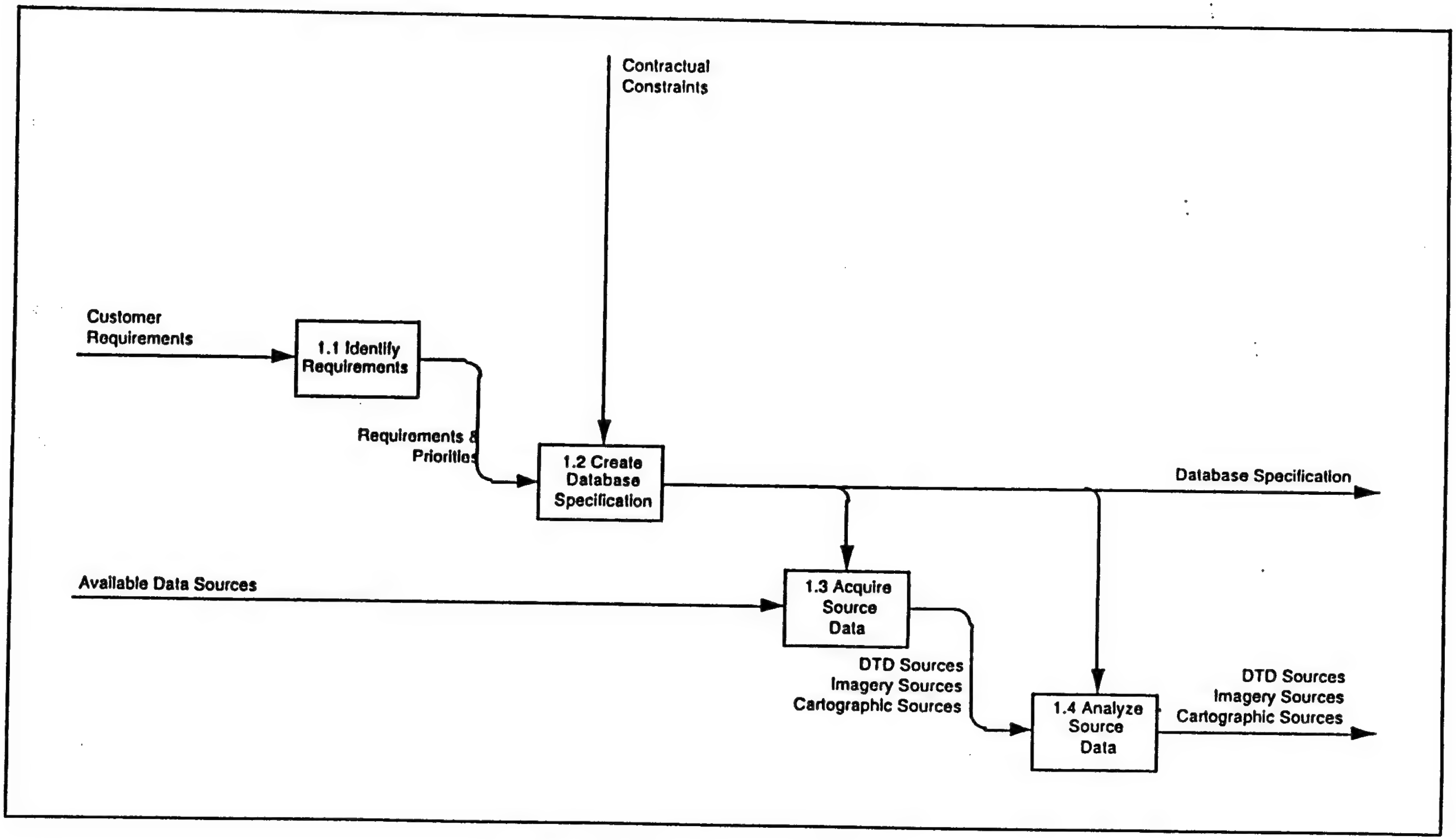

Figure 16. Data Base Specification

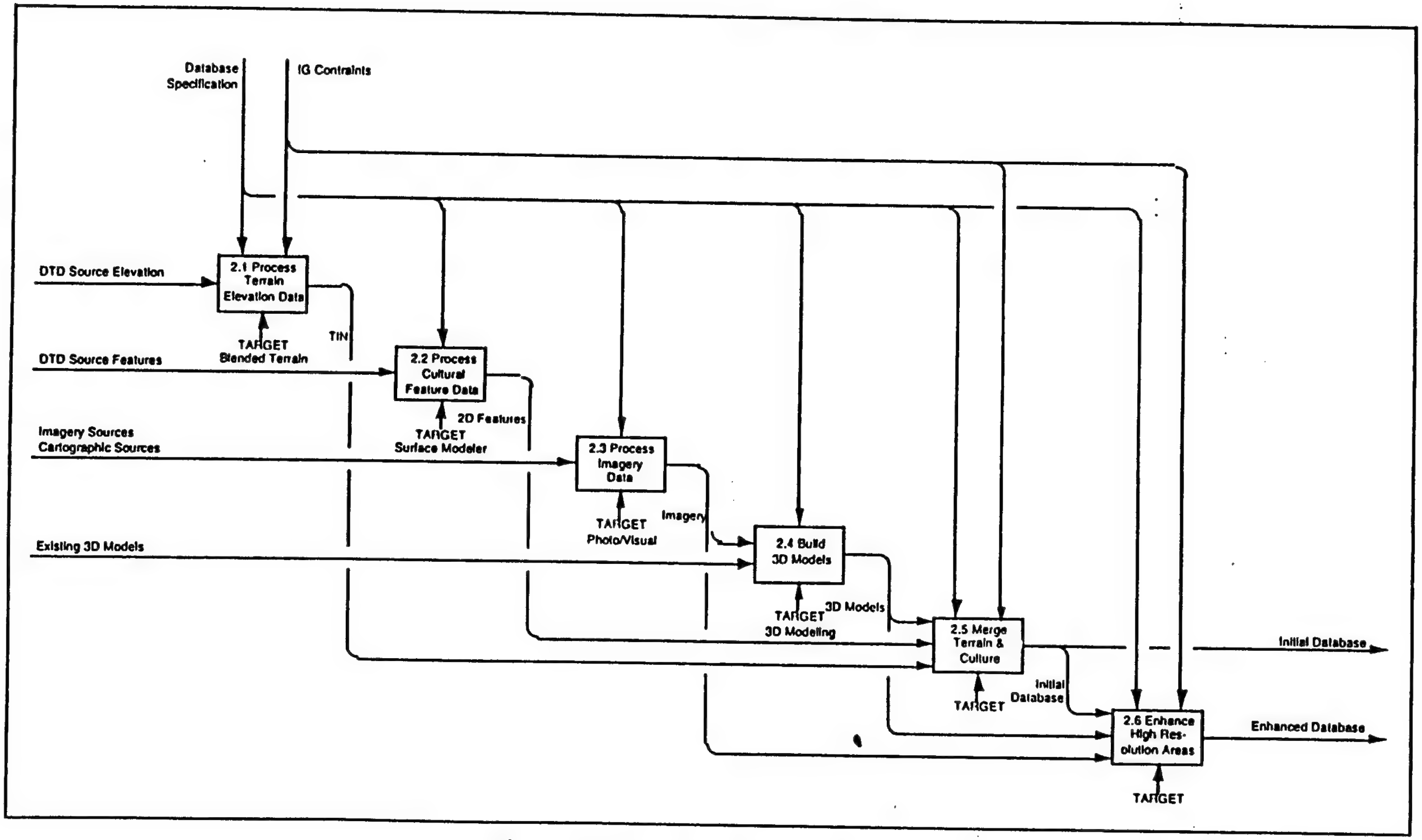

Figure 17. Data Base Generation

• The total number of triangular faces

• The average number of faces per square nmi

• A specified error tolerance.

A terrain roughness table (based on maximum and standard deviation of elevation) is used to vary the TINning criteria according to varying terrain roughness. However, in general, all of the original DTED elevation posts are retained in the TIN. The TIN generation rules are optimized for the CompuScene V image generator. For other image generator types, various parameters are adjusted. A specific block can be triangulated at multiple levels of detail using different stopping criteria. The TARGET Blended Terrain component also has the capability to incorporate topographic features, such as peaks, ridge lines, and contour lines as constraints in the TINning algorithm, and to perform cut and fill operations.

An "attribute" file is used to control the use of DFAD features, specifying which features are to be used based on their FID codes. In general, point features that have non-zero vertical height are retained, along with all linear and areal features. Thinning of features can be done either during DFAD import or later. The "attribute" file also supplies default attribute values, which may be overridden by the actual attribute values. In general, all DFAD attributes are retained in the internal data base even if they are not used in generating the image generator run-time data base. FAC codes and most feature heights are examples of this. These attributes, augmented with defaults, are used when DFAD is output.

Three types of 3-D models can be created:

• Moving models—e.g. aircraft

• Universal or Generic models—trees, cacti, and typical buildings, which are "scattered" over appropriate areas within the data base

• Fixed models—unique, geospecific models that correspond to particular features contained in the imagery, particularly for the high resolution enhanced areas of a data base.

The merging of features and terrain for the majority of the data base coverage area is straightforward. Area and linear features are simply laid over the TIN surface, and selected point features are used to position 3-D models. In the enhanced high resolution areas, however, the DFAD background features are removed and replaced with geospecific texture derived from imagery. This imagery also is used to digitize features within the high resolution area, and to create and position geospecific 3-D models.

2.3.3.3 Data Base Formatting

This phase involves the formatting of image generator run-time data bases, radar run-time data bases, and other outputs such as NIMA DTED and DFAD and SIF data bases. The activities that make up this phase include:

- Formatting IG data bases, in which run-time data bases for the CompuScene V and other image generators are created, as well as MultiGen® OpenFlight™ and other SGI format data bases

- Generating DMA data bases, in which data is output in DMA DTED and DFAD formats, using defaults to fill in missing attributes

- Formatting Radar data bases, in which radar run-time data bases are created for the MH-53J, MH-60G, and C-130 radar simulators

- Formatting SIF data bases, in which data is output in SSDB SIF.

The relationships among these activities, and their inputs and outputs, are shown in Figure 18.

2.3.3.4 Testing

This phase involves the various testing, quality assurance, and configuration management activities performed relative to a particular terrain data base. The activities that make up this phase include:

- Customer Review, in which users and subject matter experts review the contents of the data base, primarily using the image generator

- Internal Quality Assurance, in which terrain data base generation system personnel perform a dress rehearsal of the Acceptance Test Procedure

- Configuration Management Build, in which a master copy of the TARGET internal data base is archived to CD-ROM, and master copies of image generator disks and other products are created

- Formal Acceptance Testing, in which the data base is formally tested and accepted (or rejected) by the Government

- Release for Government Training, in which the terrain data base products are formally released for use in training aircrews.

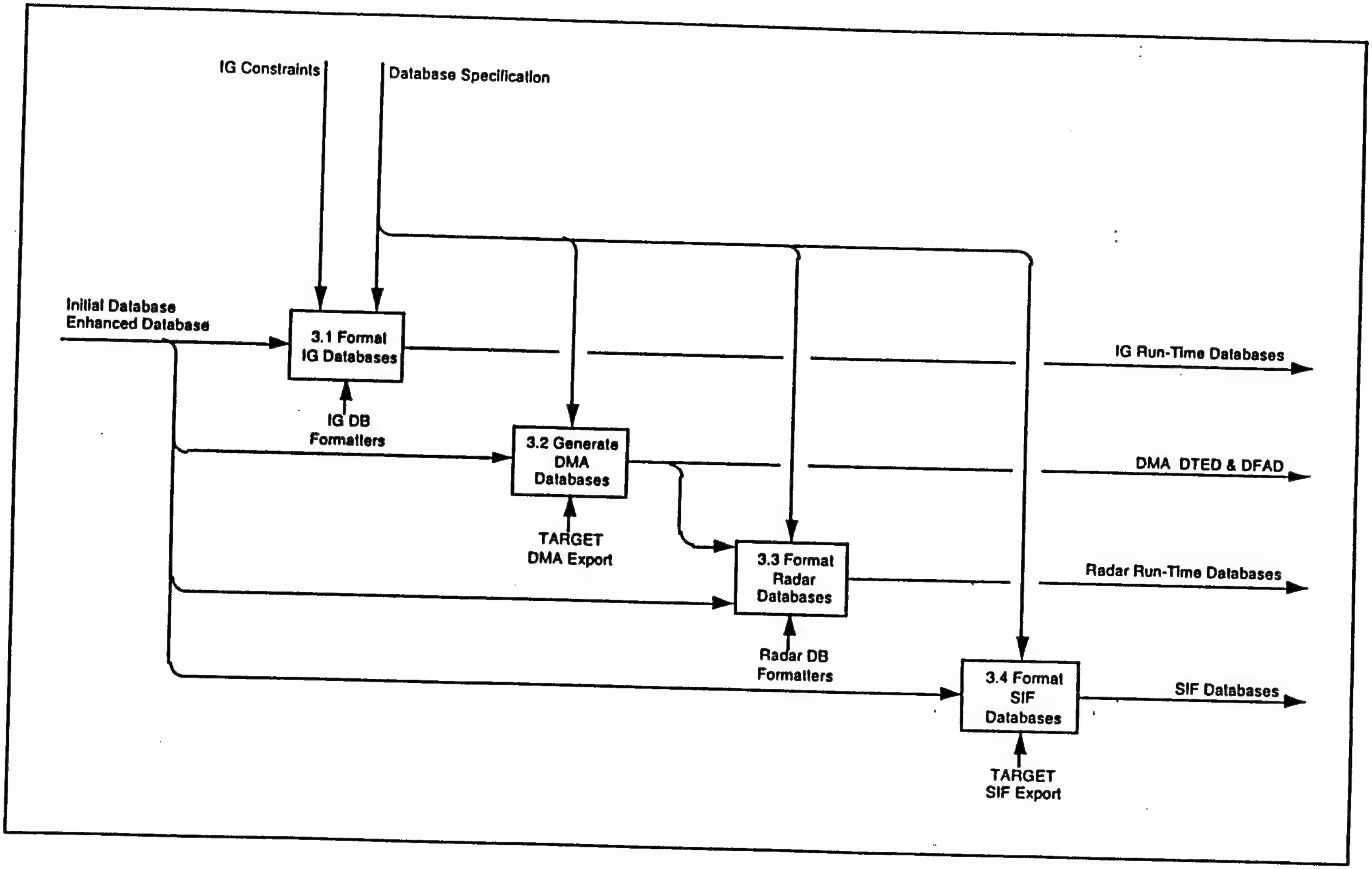

Figure 18. Data Base Formatting

The relationships among these activities, and their inputs and outputs, are shown in Figure 19.

2.3.3.5 Data Base Maintenance

This phase involves updating existing data bases and correcting data base errors that are reported by users, and associated reprocessing and configuration management of the terrain data base and the products derived from it, including image generator and radar simulator run-time data bases.

2.3.4 TOOLS

The principal tool used in the MTSS terrain data base generation process is the TARGET software, developed by Lockheed Martin, Orlando, FL; running on Sun workstations, that include the following components:

- Photo/Visual Generation System—used for image processing, including the identification of control points and tie points, resampling, warping, creation of insets, etc.

- 3-D Modeling Systems used for creating 3-D models

- Blended Terrain—used for creating and editing an internal TIN representation from gridded terrain elevation source data

- Surface Modeler—used for manipulation and editing of feature data, including edge matching, connecting roads and rivers into networks, digitizing features from imagery, etc.

- Cell Texture—used for creating both generic and specific cell texture maps

- NIMA Import/Export—used to import and export terrain elevation data in DTED format, and terrain feature data in DFAD format, controlled by an attribute file, which specifies which FID codes are to be included.

The relationships among these tools, and how they fit into the data base generation process, is shown in Figure 20. The box simply labeled "TARGET" represents all of the main editing functions of the TARGET tool set, including the Surface Modeler and the Blended Terrain components.

The various components of the TARGET software operate either interactively or in batch mode, as appropriate. TARGET stores all data in a single, integrated internal data base, in geographic coordinates. In general, it is possible to view and edit any type of data (elevation, features, imagery, and models) while using any of the other types as background.

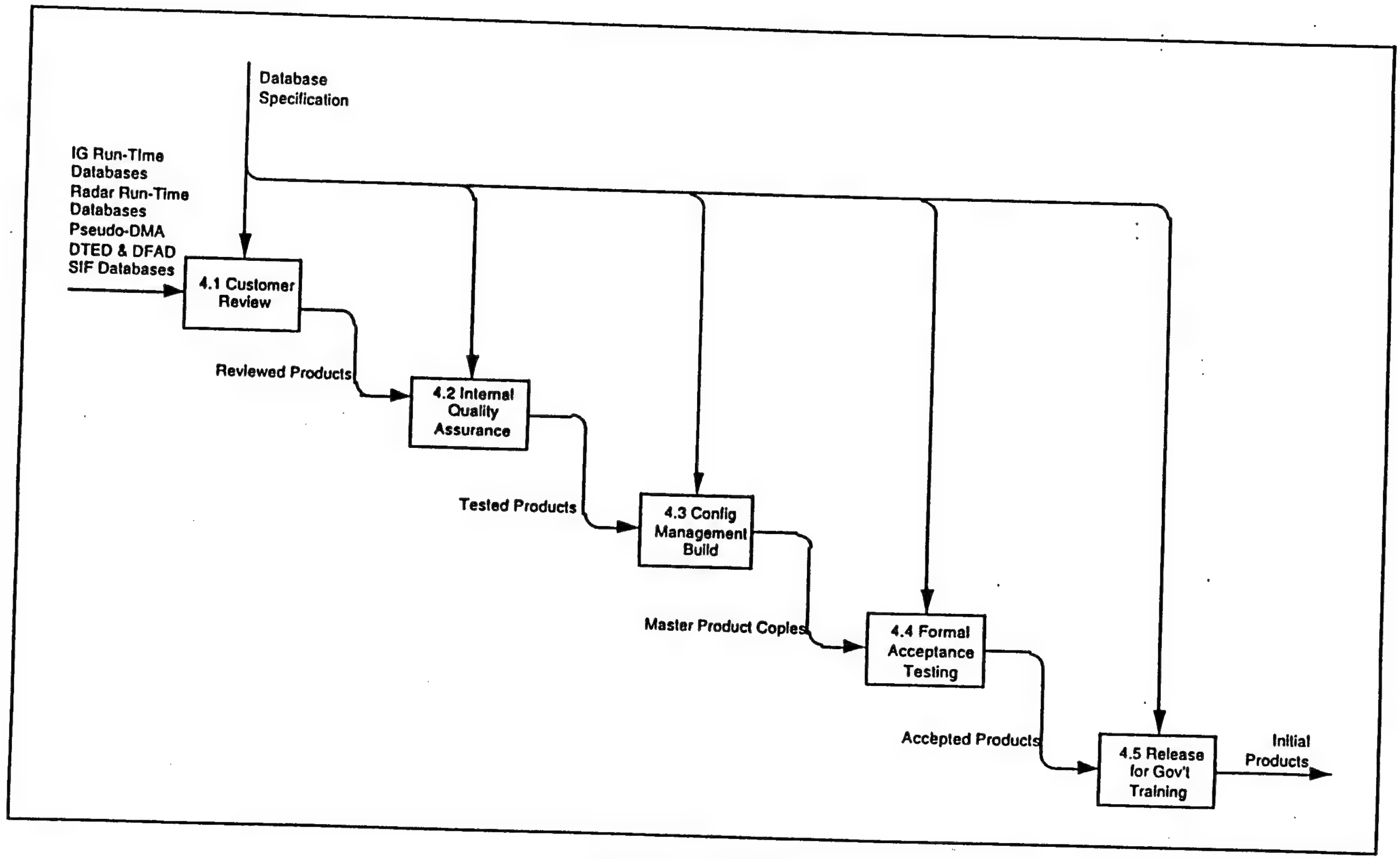

Figure 19. Testing

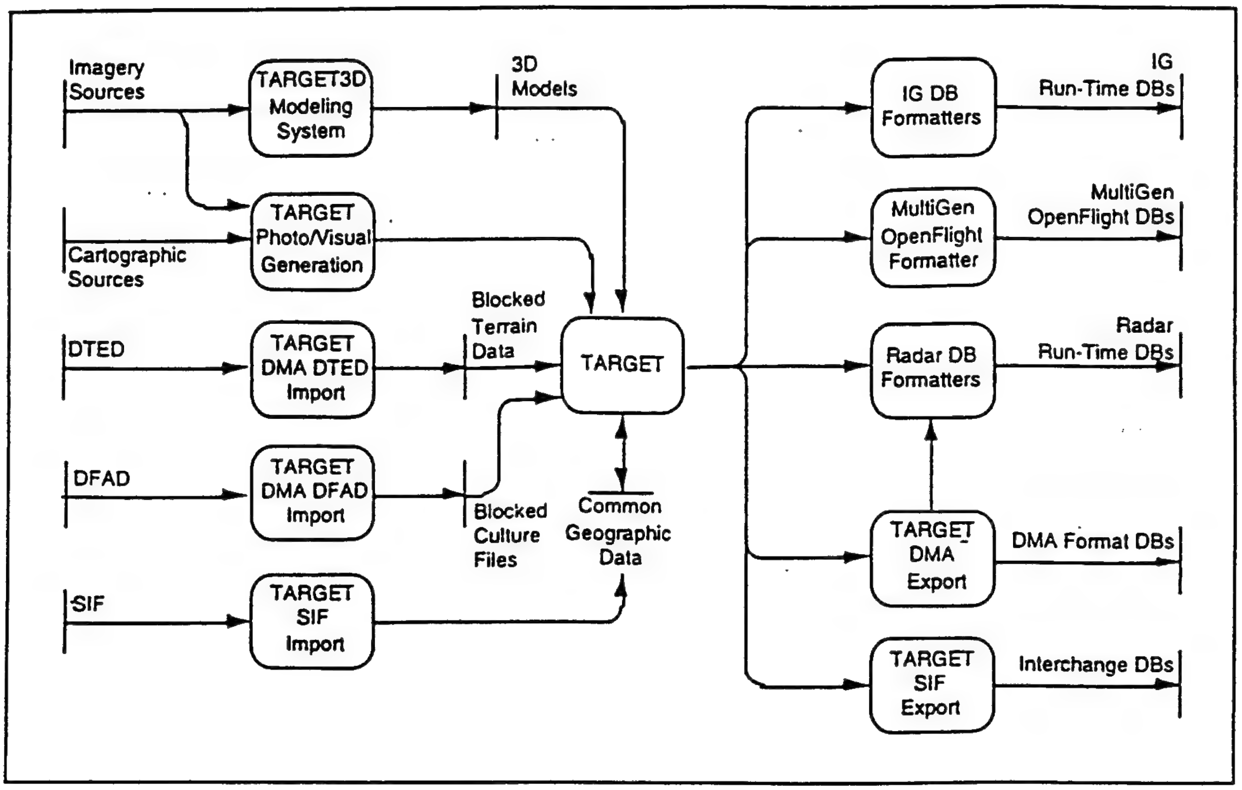

Figure 20. MTSS Terrain DBGS Data Flows

Other tools used in the MTSS terrain data base generation process include:

• Trifid image processing software, sometimes used because it is better at controlling images than the TARGET software

• Low-cost Exploitation Operations Workstation (LEOW), originally developed by GE, now called the Data Manipulation tool of Electronic Light Table (ELT) 6000, which is used for mensuration of image

• A flatbed scanner with 3 micron resolution and a granite bed, used for scanning hardcopy (including film) imagery and cartographic sources.

The MTSS also will be getting a copy of E&S's EaSIEST software to support the ESIG 4000 image generator that is expected to arrive in early 1996.

No commercial GIS system is used in the MTSS terrain data base generation system.

2.3.5 MANAGEMENT

The MTSS is operated by 220 on-site contractor personnel, integrated with the 74 Government personnel of the 58th Training Support Squadron. Approximately 20 contract personnel are primarily affiliated with terrain data base generation. The remainder of the personnel staff the other parts of the MTSS, including the SDBF, operation and maintenance of the various simulators and associated equipment, and logistics, security, and administrative support.

As an ongoing background task, the MTSS terrain data base generation system is required to produce 60,000 square nmi of data base coverage every month. In addition to this, specific surge tasking may be invoked to generate data bases to meet specific mission rehearsal or training requirements. These "surge" efforts are typically required to produce a data base covering six 1 degree by 1 degree cells, with several small, embedded high resolution areas within five days. This involves approximately 20 people working 12-20 hour days. The majority of the time and effort is spent working on the high resolution, imagery-enhanced areas, creating 3-D feature models, and ensuring that polygon budget priorities and tradeoffs are met.

In general, data base generation personnel rotate among the different types of processing tasks (terrain, culture, imagery, models), but some end up specializing in particular areas where they are most effective.

The MTSS terrain data base generation process makes extensive use of internal standards to facilitate the rapid development of terrain data bases. These include standard default values for all DFAD feature attributes, a standard library of 3-D feature models for all DFAD features, and standard data base documentation templates.

2.3.6 PROBLEMS & ISSUES

The most significant problems and issues related to DTD products that were identified by the personnel who operate the MTSS terrain data base generation system are:

1. The lack of data availability is, overall, the most important problem. The MTSS needs world-wide, medium-resolution coverage for both terrain elevation and feature data. One of the key lessons learned from the history of special operations forces is the importance of good intelligence data, including terrain data, in support of mission rehearsal for special operations. In past operations where good data was available and good mission rehearsal was performed, such as for the Son Tay Prison raid in 1970, mission execution has been near-perfect and losses have been minimal. On the other hand, when data was not available to support mission rehearsal, such as for the Myaguez rescue in 1975, or the Iran hostage rescue in 1980, mission execution has been disastrous, with losses sometimes greater than the size of the group that was to be rescued. In general, having some data is always better than none. Negative training effects because of lack of data accuracy can be avoided by training aircrews using both simulator data bases and the actual flights over the

same areas, so that the differences between simulator data bases and the real world are familiar to the aircrews, and their expectations are realistic

2. The lack of correlation between terrain elevation and cultural feature data also is a serious problem, particularly for the high-resolution areas

3. A standard product with world-wide imagery coverage, such as CIB, would be extremely valuable. Such a product would be used in preference to DFAD to provide geospecific texture for most areas, though key areas still would be enhanced with higher resolution image. However, this approach would not be compatible with the current image generator hardware used by the MTSS, and also would not necessarily support the generation of correlated infrared and radar data bases adequately

4. The lack of correlation between different features, including inconsistencies at cell edges, etc., cause problems. Whenever data is available from multiple sources, is it important to know which features and sources are more accurate, since moving features may cause problems with respect to mission rehearsal

5. Data currency, the age of the data, also are a concern. The high resolution imagery used for the enhanced areas tends to be recent, therefore, showing the age of the DFAD data.

The stability of NIMA standards, products, and processes over time is very important to the cost of data base generation. Having to deal with many different standard products, which are available for different locations because of their ages, significantly complicates the terrain data base generation process.

2.4 SOF ATS TERRAIN DBGS

The SOF ATS, Hurlburt Field, FL, is operated by the USSOCOM, and provides aircrew training and mission rehearsal support to the USAF 16th SOW, and other special operations units. The SOF ATS was developed and is operated by Loral Defense Systems, Akron, OH.

The SOF ATS terrain data base generation system was designed to develop very large, high fidelity terrain data bases, to support an MC-130H flight simulator. These data bases are contractually required to include four levels of detail:

1. Background area—Any shape, with an area of approximately 500,000 square nmi, with feature density and terrain consistent with Digital Chart of the World (DCW) at 1:1,000,000-scale, or, where available, DTED Level 1 and DFAD Level 1, at 1:250,000-scale, with 100-m elevation post spacing, and generic texture with 10-m resolution

2. Flight corridors—20 nmi wide and totaling up to 25,000 square nmi in length, with feature density in the central 10 nmi wide strip consistent with the content of a 1:250,000-scale Joint Operations Graphic—Air (JOG-A), i.e., DTED Level 1 and DFAD Level 1, and the 5 nmi wide strips on either side feathered into the background area, with 100-m elevation post spacing, and generic 10-m texture

3. Navigation waypoints—60 to 80 in a data base, each 3 nmi by 3 nmi in area, with feature density consistent with the content of a JOG-A, plus, where available in the source data, at least four specific navigation or radar significant 3-D objects, with 25-m elevation post spacing, and geospecific photo-based texture with 1.25-m resolution

4. Target areas, at least three in a data base, each consisting of a high resolution 2 nmi by 2 nmi area containing at least 500 generic features per square nmi and, where available in the source data, 20 specific 3-D features, and a feathered area, 6 nmi by 6 nmi, where the feature density blends into the surrounding area, with 25-m elevation post spacing, and geospecific photo-based texture with 1.25-m resolution

The SOF ATS terrain data base generation system is designed to produce a data base such as that described above in 48 hours, and is therefore highly automated, with many tasks being performed in parallel in a tightly coordinated manner. Labor intensive operations are avoided. The collocated SOFPREP facility, which is operated by USSOCOM, maintains a library of all available NIMA DTD, as well as imagery and cartographic sources for use by the SOF ATS terrain DBGS. The 48-hour time period starts when SOFPREP delivers all available source data to the SOF ATS terrain DBGS.

The SOF ATS terrain DBGS stores all data in an internal data base. This data base is organized in four correlated layers: 1) terrain elevation data in gridded format; 2) vector features with attributes in ARC/INFO format, organized into point, line, and area feature coverages; 3) image-based texture; and 4) 3-D models of features, both generic ("universal") and specific. Editors for each layer allow the data that it contains to be manipulated, also while viewing one or more of the other layers. The internal data base is stored in geographic coordinates, relative to the WGS84 ellipsoid, with a resolution of 1/1000 of an arc-second (approximately 1 inch). Feature and attribute codes in the internal data base are based on an expanded set of DFAD feature codes and attributes. Elevation data is stored at one arc second resolution (DTED Level 1 is upsampled). The internal data base contains a superset of all the information necessary to create the run-time visual, infrared, and radar data bases.

The SOF ATS terrain DBGS is designed to primarily support a high-end E&S ESIG-4000 image generator. This image generator has the unique capability to dynamically integrate gridded elevation data and vector feature data, plus image texture and 3-D models, in real time. As a result, unlike the other terrain data base generation systems covered in this report, the SOF ATS terrain DBGS never explicitly converts terrain elevation and feature data into polygons. Also, the terrain under 3-D models does not have to be flattened.

2.4.1 INPUT SOURCES

The data sources that can be used by the SOF ATS terrain data base generation system are clearly defined in the contract under which the system is operated. Only those sources specified in the contract can be used.

The SOF ATS terrain data base generation process uses several different types of sources, including:

- DTD sources
- Imagery sources
- Cartographic sources.

Each of these is discussed below.

2.4.1.1 DTD Sources

The SOF ATS terrain DBGS uses standard NIMA DTD products as its preferred data sources at all levels of resolution. The DTD sources used in the SOF ATS terrain DBGS include:

- NIMA DTED Level 1 and Level 2
- NIMA DFAD Level 1 (or 1C) and Level 2 (or 3C)
- NIMA ITD
- NIMA DCW.

DTD in SSDB SIF also can be input by the SOF ATS terrain data base generation system, however it is not yet an approved source.

Higher resolution DTD sources (i.e., Levels 3, 4 or 5) would be desirable in the future, as the system's accuracy is limited by the accuracy of the source data. For the target areas, in particular, there cannot be too much detail.

NIMA Digital Terrain Elevation Data (DTED)

For the background area and flight corridors, DTED Level 1 is the preferred source for elevation data. DCW is an alternate source of elevation data where DTED is not available, along with cartographic and stereo imagery sources.

For navigation waypoints and target areas, DTED Level 2 is the preferred source for elevation data. Where DTED Level 2 is not available, elevation data is extracted from stereo imagery.

NIMA Digital Feature Analysis Data (DFAD)

For the background area and flight corridors, DFAD Level 1 (or 1C), Second Edition is the preferred source for feature data. DFAD First Edition is used when Second Edition is not available. Alternate sources for feature data, in priority order, are DFAD First Edition, DCW, and cartographic sources. DFAD also is used as a source of generic texture, based on surface material information, for the flight corridors.

For navigation waypoints and target areas, DFAD Level 2, Second Edition (or Level 3C), or stereo imagery, are the preferred sources for feature data.

NIMA Interim Terrain Data (ITD)

ITD is used as an alternative source of feature data for navigation waypoints and target areas where it is available. When ITD is used, only those ITD features and attributes that can be mapped to DFAD features and attributes are retained.

NIMA Digital Chart of the World (DCW)

DCW is an alternative source of feature data for the background area and flight corridors. DCW also is used as a source of generic texture for the background area, and as an alternative source of elevation data for the background area. Mapping the free-form attribution in DCW to the DFAD-based feature and attribute coding used in the SOF ATS terrain DBGS internal data base is a problem.

2.4.1.2 Imagery Sources

The types of imagery sources used include:

- National imagery
- Airborne imagery from reconnaissance cameras
- SPOT imagery
- Landsat imagery.

Although DTED Level 2 and DFAD Level 2 are the generally preferred sources of terrain elevation and feature data for navigation waypoints and target areas, because of the ease with

which these sources can be used, stereo imagery also is commonly used for this purpose, either because high-resolution DTD is not available, or because the stereo imagery is more current and accurate than the available DTD sources. Stereo imagery from reconnaissance cameras and national sources is used for this purpose, in both digital and hardcopy form.

Imagery also is used as geospecific texture. High-resolution (1.25 m) imagery is used as texture for navigation waypoints and target areas. SPOT imagery is used as texture in the flight corridors. Landsat imagery may be used as texture for the background area.

CIB is not currently on the list of approved data sources for the SOF ATS terrain DBGS, but is expected to be added in the near future, to be used as geospecific texture for flight corridors and the background area.

2.4.1.3 Cartographic Sources

Cartographic sources are used as an alternate source of both elevation and feature information for flight corridors, where DTED Level 1 and/or DFAD Level 1 is not available. This includes all types of hardcopy maps, as well as ADRG. Although the SOFPREP facility maintains a complete collection of all ADRG CD-ROMs, ADRG is not commonly used, as it is easier to scan a hardcopy map and separate the colors using software than it is to use the ADRG. ADRG, particularly that derived from 1:250,000-scale JOGs, is useful for reference.

2.4.2 OUTPUT PRODUCTS

The primary output products from the SOF ATS terrain data base generation system include:

- Run-time data bases for the E&S ESIG-4000 image generator, supporting the creation of both visual and infrared views

- Run-time data bases for the MC-130H radar simulator, which is based on custom hardware developed by Loral

- Interchange data bases in the SSDB SIF.

Each of these types of products is described briefly below.

The primary output produced by the SOF ATS terrain data base generation system are the run-time data bases that support the ESIG-4000 image generator (IG). This image generator has some unique capabilities in that it can combine gridded terrain elevation data and vector feature data with geospecific texture and 3-D models in real time. A separate channel supports the generation of correlated infrared views. The ESIG-4000 uses Cartesian coordinates. The data

from the internal data base, which is in geographic coordinates, is projected using either a Lambert or Mercator projection. Elevation data and image texture is resampled.

Unfortunately, the SOF ATS facility has not yet received its ESIG-4000 system, so that data bases produced at the facility must currently be taken elsewhere to be viewed fully.

The SOF ATS terrain data base generation system also can feed other types of image generators, such as the ESIG-3000, or the Lockheed Martin PT-2000, by exporting terrain elevation, vector features, image texture, and 3-D models from the internal data base, to either the EaSIEST tool set or the TARGET tool set, respectively. Other visualization systems such as TopScene also may be supported. Videos also can be produced.

Run-time data bases for the MC-130H radar, which are correlated with the corresponding visual and infrared data bases, are produced using data extracted from the internal data base, and formatted for use by the radar simulator.

Data bases in the SSDB SIF, as defined in MIL-STD-1821, may be created, containing gridded elevation data, 2-D and 3-D vector feature data, and 3-D models. These data bases may be produced to allow SOF ATS terrain data bases to be used by other flight simulators.

Data bases to support SAF systems are not currently produced by the SOF ATS terrain DBGS, but this capability is being developed.

Also being planned is the ability to output several standard NIMA DTD products, including DTED, DFAD, ITD (by expanding attribution), and vector data in VPF.

2.4.3 PROCESS

As shown in Figure 21, the SOF ATS terrain data base generation process consists of three major phases:

1. Preparation, in which the data base generation process is simulated to create a schedule of data base generation tasks, and the available source data is obtained from SOFPREP

2. Data Base Generation, in which the source data is processed and the internal data base is populated

3. Data Base Formatting, in which the run-time visual/infrared and radar data bases are formatted, SIF Data Bases are created, and the internal data base is archived.

The first phase is concerned with preliminary activities. The second phase is concerned with processing the various source data elements and populating the internal data base. The third

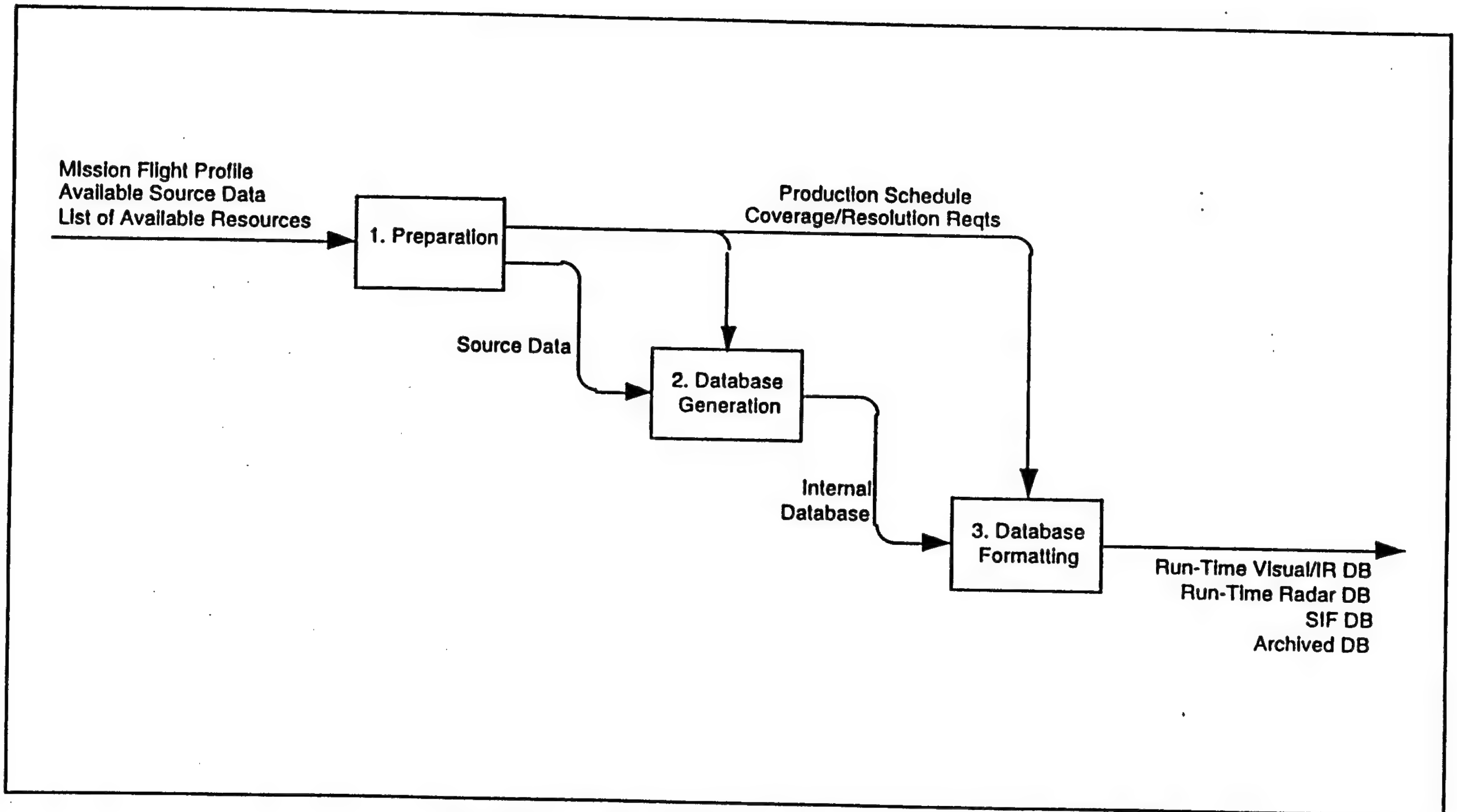

Figure 21. SOF ATS Terrain DB Generation Process

phase is concerned with generating the products of the process. At least thus far, the SOF ATS terrain DBGS has not had to be concerned with the distribution or maintenance of products to any significant degree.

2.4.3.1 Preparation

This phase consists of preliminary activities performed before the actual execution of the terrain data base generation process. These activities include:

- Determining Data Requirements, in which the coverage and resolution requirements of the data base are determined from the mission flight profile, including the locations of flight corridors, navigation waypoints, and target areas

- Creating Production Schedule, in which a simulation model of the SOF ATS terrain DBGS is used to optimally schedule all of the individual data base generation tasks that must be performed in order to meet the data base coverage and resolution requirements

- Data Acquisitioning, in which the source data necessary to meet the data base coverage and resolution requirements is obtained from the SOFPREP library.

The relationships among these activities, and their inputs and outputs, are shown in Figure 22.

Given the mission flight profile, including routes, waypoints, and targets, the Flight Profiler determines the required overall extent of the data base and the requirements for high level of detail inserts for the waypoints and targets. Data sources are selected from prioritized lists for each resolution level, based on availability. The background area and flight corridors, which collectively are considered to be the low-resolution areas of the data base, are organized around a grid of 1 degree by 1 degree geocells.

Wherever a flight corridor passes through a geocell for which DFAD is available, that entire geocell is represented at that higher resolution. When DFAD is not available and a cartographic or imagery source must be digitized to support a flight corridor, only the corridor itself is represented at the higher resolution, while the remainder of the geocell is part of the background area. In practice, flight corridors are difficult to predict, except for training scenarios, and may not be very important, except for the final approach to the target area. The background area, including those geocells which contain no flight corridors, is modeled using DCW.

The high resolution areas, including navigation waypoints and target areas, are constructed according to their defined sizes and locations, independent of the geocell grid. Again, data sources are selected according to a prioritized list, with imagery being preferred for the high resolution areas.

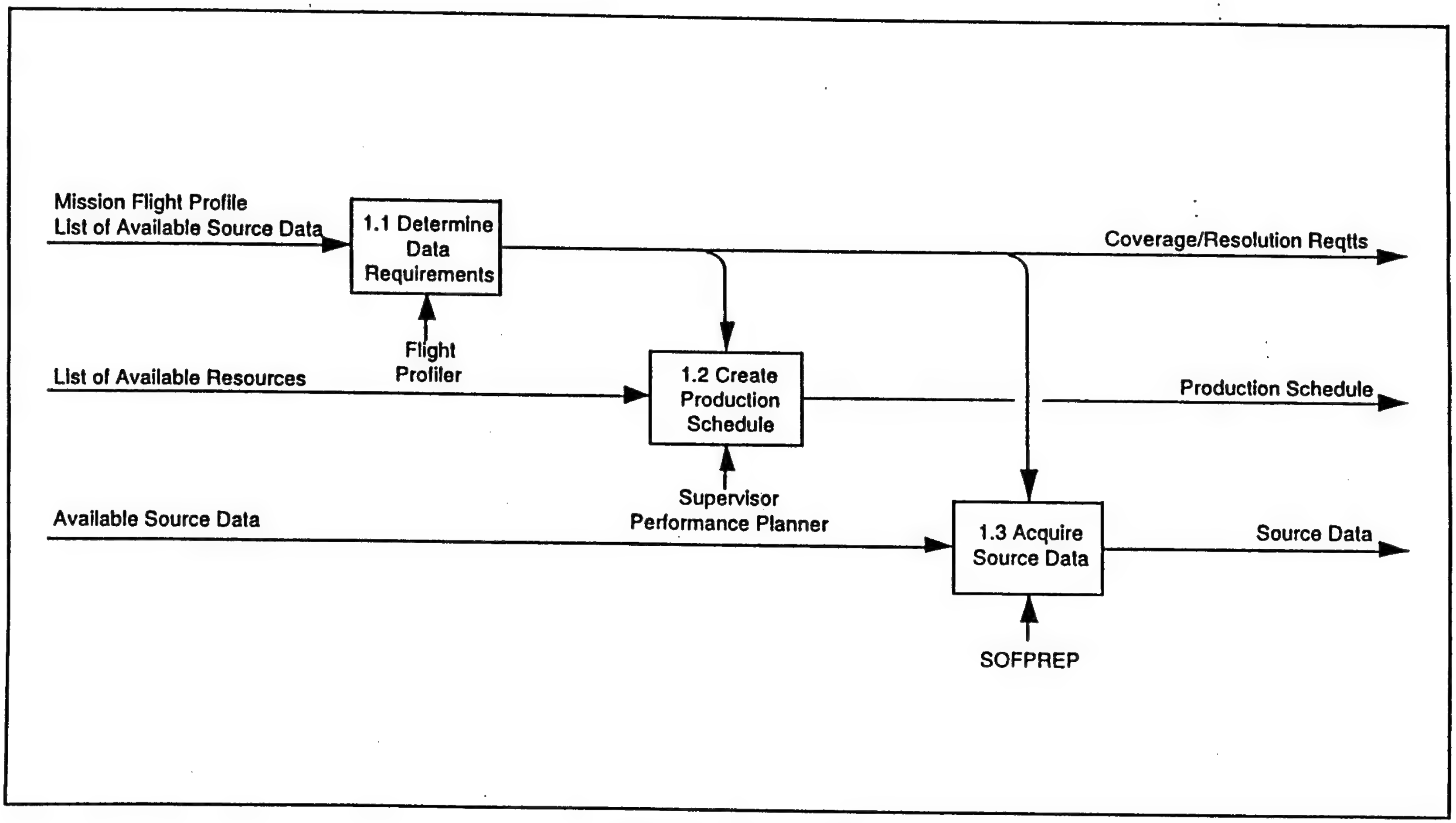

Figure 22. Preparation

The Supervisor Performance Planner uses a simulation model of the SOF ATS terrain DBGS to determine the optimal schedule for the terrain data base generation process. This simulation uses descriptions of the available resources, including hardware, software, and personnel, as well as a model of the terrain data base generation process, and a historical data base of performance times for each type of task. The model of the process is combined with the data base coverage and resolution requirements to identify all of the individual tasks that must be performed, and then a production schedule is created to control the performance of all of those tasks.

Finally, the data base coverage and resolution requirements are used to obtain the necessary source data from the SOFPREP library.

2.4.3.2 Data Base Generation

This phase involves the creation of the internal data base from the various types of source data, including both the low-resolution areas (background and flight corridors) and the high-resolution areas (waypoints and target areas). These activities include:

- Low-Resolution Processing, in which feature and elevation data for each geocell is loaded from sources such as DFAD, DTED, and DCW, and edge matched along geocell boundaries

- High-Resolution Build, in which features, elevation, geospecific texture, and 3-D models are extracted from stereo imagery, monoscopic imagery, or other sources

- High-Resolution Merge, in which first feature coverages are merged, and then elevation, geospecific texture, and 3-D models of features are merged, with quality control checks at each step

- Low-Resolution/High-Resolution Merge, in which high-resolution areas are merged into the low-resolution background, including elevation, texture, and features, and edge-matched and blended across the boundaries of the high-resolution area.

The relationships among these activities, and their inputs and outputs, are shown in Figure 23.

Normally, low-resolution processing simply involves loading in the DFAD and DTED files, or DCW data, for each geocell, and edge-matching elevation and features along the geocell boundaries. Edge matching is done starting in the southwest corner of the data base, proceeding diagonally to the north and east. DFAD features are not normally generalized, except for final editing when the run-time image generator data base is being created. ITD and feature data digitized from cartographic or imagery sources is commonly generalized, however, to reduce its density.

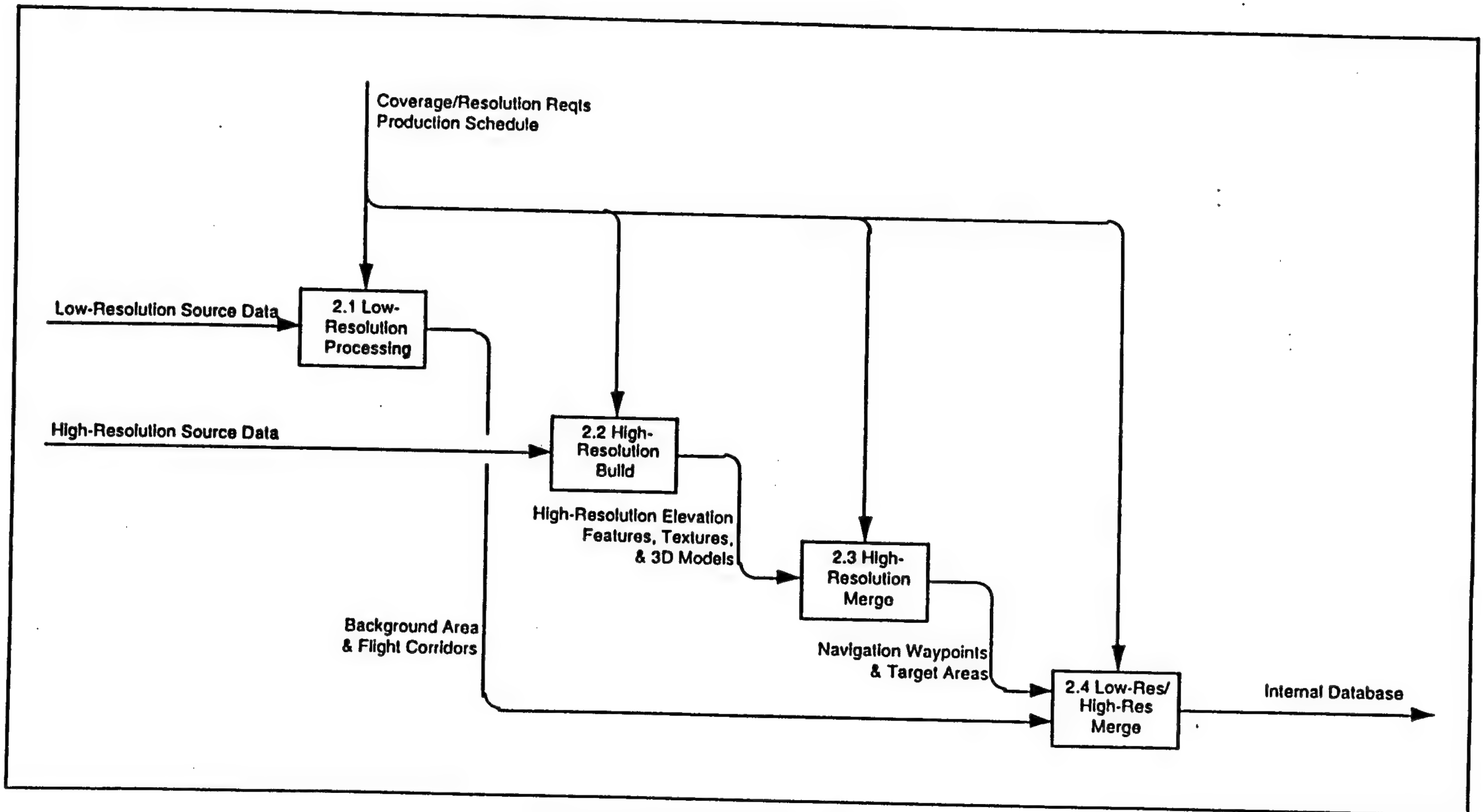

Figure 23. Data Base Generation

The high-resolution processing is much more elaborate. Elevation data is extracted from stereo imagery if possible, or may come from DTED Level 2, or from contour lines extracted from cartographic sources. In this latter case, TINs are used as an intermediate form to derive elevation data in gridded form.

Features also are extracted from stereo imagery, obtained from DFAD Level 2 (or 3C) or ITD, or digitized from monoscopic imagery or cartographic sources.

Geospecific 3-D models are constructed from stereo imagery, or built using AutoCAD™. Three-dimensional models are referenced to ARC/INFO point features, for both generic (a.k.a. universal) and geospecific features.

Once all of the high-resolution data elements for a particular area have been created, they are merged together to create a 3-D representation of a waypoint or target area. The point, line, and area feature layers are merged, elevation and texture patches are merged, and 3-D models are positioned.

Finally, the high-resolution inserts are merged into the low-resolution background. Whenever data of different resolutions is combined, the lower resolution data is edited to match the higher resolution data. Where data of different resolutions overlap, the lower resolution data is discarded. Elevation, features, and texture information is pasted into the background, replacing the low-resolution data occupying the same area. The edges of the high-resolution area are edge matched with the background, with respect to elevation, features, and texture. The area surrounding the high-resolution patch is then blended with the high-resolution data to make the edges of the high-resolution area less obvious.

2.4.3.3 Data Base Formatting

This phase involves the formatting of image generator run-time data bases, radar simulator run-time data bases, and other outputs such as SIF data bases. The activities that make up this phase include:

- Visual/IR DB Formatting, in which the run-time visual (and infrared) image generator data base is created from the internal data base

- Radar DB Formatting in which the run-time radar simulator data base is created from the internal data base

- SIF DB Formatting, in which data is output in SSDB SIF

- Data Base Archiving, in which the internal data base is archived for future use.

The relationships among these activities, and their inputs and outputs, are shown in Figure 24.

2.4.4 TOOLS

The SOF ATS terrain data base generation system is an integrated network of workstations and servers which includes the following major components:

- Five MicroVAX-based Image Processing Workstations developed by GDE (the same type used by NIMA), which are used for softcopy image control, rectification, and stereo feature extraction, producing 2-D and 3-D feature models with texture, feature attributes, rectified image patches and mosaics to use as geospecific ground texture, and gridded elevation data

- The Image Data Input System, with multiple tape drives for softcopy imagery input, and a scanner, for hardcopy imagery input

- The Image Data Storage System, with a high-speed, 14GB disk

- Five Sun SPARC station-based Graphics Workstations, each with a stereo monitor and a digitizing table, running ARC/INFO, AutoCAD™, and other software integrated underneath a custom graphical user interface. They are used for DTD and cartographic source data assembly, editing the output products of the Image Processing Workstations, digitizing features from hardcopy maps or imagery, producing texture and feature data from multispectral imagery, and performing quality control on the final data base

- Two Scanner Workstations, for color hardcopy map input, with software that vectorizes and attributes the scanned map data

- One Sun workstation which runs E&S's EaSIEST tool set, which is used to create 3-D models and "themals," which are generic clusters of 3-D models (e.g. a farm, perhaps consisting of a house, a barn, and several smaller buildings) that are distributed randomly within an appropriate geographic area

- The Graphics Source Processing System, a Solbourne Sun-compatible server, used for the loading of DTD sources from magnetic tape or CD-ROM

- The Data Base Transform System, another Solbourne Sun-compatible server, used to generate the visual/infrared and radar run-time data bases

- One Sun SPARC station-based supervisor workstation, which uses the mission flight profile to determine what coverage areas must be represented at each resolution, and then

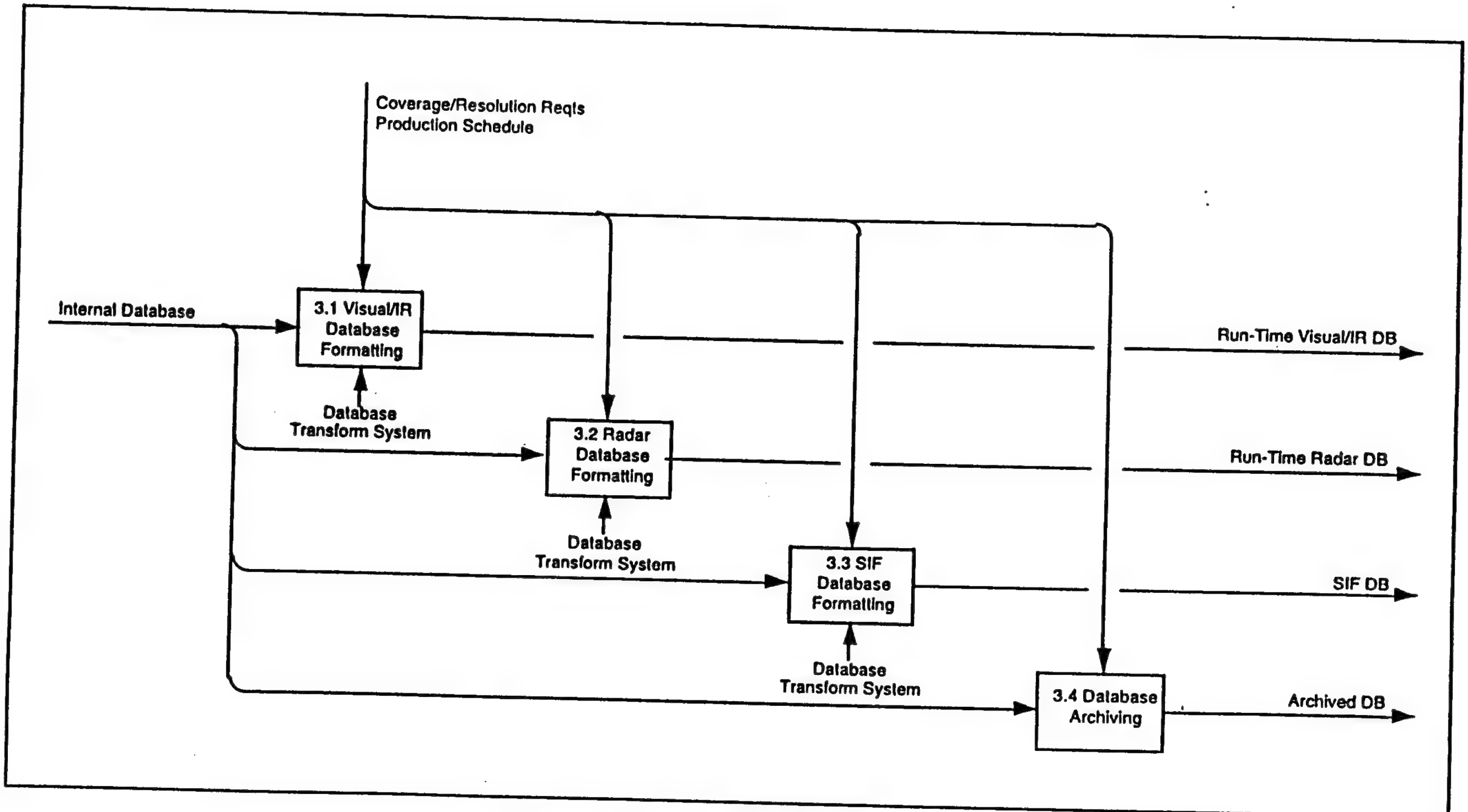

Figure 24. Data Base Formatting

uses this information, along with the list of available data sources and source preferences, and descriptions of the available processing resources (workstations, servers, memory, disk space, and software licenses), to schedule all of the 1,000 to 2,000 individual tasks that go into creating a data base, using historical data to predict the time required for each task.

The supervisor workstation is the heart of the overall system, prompting the loading of source data and scheduling tasks on each of the image processing and graphics workstations. It performs configuration management of the internal data base, allowing variable-sized areas being checked out to be processed. It also provides graphical representations of the status of the data base generation process, indicating the current completion status of each cell within a data base.

The relationships among these components, and how they fit into the data base generation process, is shown in Figure 25.

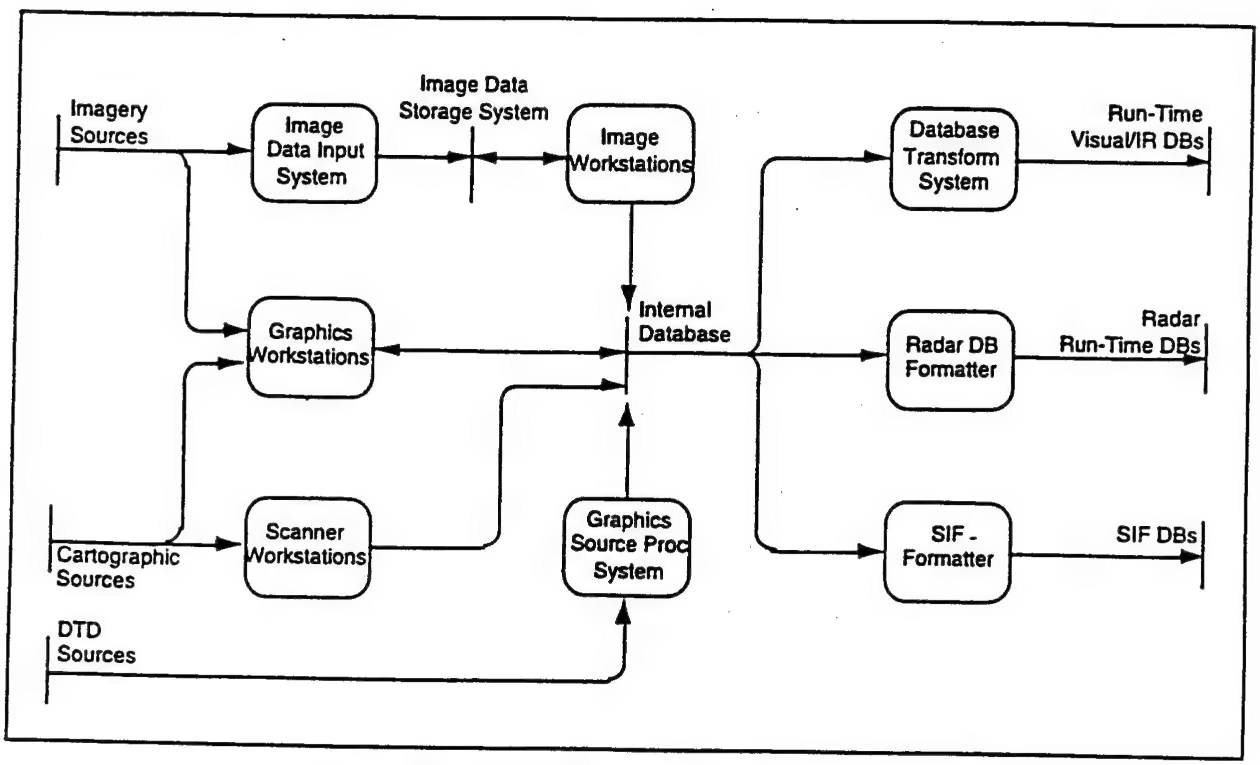

Figure 25. SOF ATS Terrain DBGS Data Flows

2.4.5 MANAGEMENT

As mentioned above, the SOF ATS terrain DBGS is required to develop a data base covering 500,000 square nmi, with up to 25,000 nmi of flight corridors, 60 to 80 navigation waypoints, and up to three target areas, in 48 hours from the time that the source data is supplied. The SOF ATS terrain DBGS currently has a staff of nine full-time personnel, with three more to be added in the near future. To support rapid data base generation in a crisis, the plan is to split these twelve primary staff into two 12-hour shifts, with additional part-time, cross-trained personnel filling in the rest of the positions.

2.4.6 PROBLEMS & ISSUES

The most significant problems and issues related to DTD products that were identified by the personnel who operate the SOF ATS terrain DBGS are:

1. DTED problems, such as spikes, raised or sunken blocks, or "corn rows" cause problems for terrain DBGS operators. Mismatches of elevation and features along DTED and DFAD cell boundaries, because of differences in sources, collection times, and/or operators, also cause problems, as do inconsistency of attribution across DFAD manuscript boundaries within a single cell. Quality control must be performed in an integrated manner, addressing not just imagery, elevation, and features separately, but all of them together.

2. Material information needs to be available for all features to support visual, infrared, and radar representations.

3. The ongoing changes in NIMA DTD products require systems such as the SOF ATS terrain DBGS to be able to adapt to new data sources, managerially and contractually as well as technically. Lack of backward compatibility between new products (e.g. VMap) and old products (e.g. DFAD) is a major concern. For example, VMap Level I will only be useful if it contains all of the attributes currently supplied by DFAD Level 1. VMap Level 2, VITD, and TTD also may be very useful, but have not been examined yet.

4. All NIMA DTD products should be made available for all training areas within the U.S. This will be a USSOCOM production requirement.

5. Standard access and exploitation software, written in Ada and/or C, should be distributed with new DTD products. This software should not make any unnecessary assumptions about the hardware capabilities possessed by the users.

6. Standard 3-D models, corresponding to DFAD feature types, would be very useful for systems such as SOF ATS. However, a means is needed to distinguish between the

different variations of such features that are found in different regions of the world. For example, a farm in the U.S. does not look like a farm in the Middle East.

It should be noted that the integration of terrain elevation and feature information is not a problem for the SOF ATS terrain DBGS because of the unique capabilities of the ESIG-4000 image generator to perform this integration on-the-fly in real time.

3. SYNTHETIC ENVIRONMENT TERRAIN DATA BASE GENERATION PROBLEMS AND ISSUES

This section identifies and discusses a number of current problems and issues related to the synthetic environment terrain data base generation process. Section 3.1 identifies a number of problems that current synthetic environment terrain data base generation processes have with the existing DTD sources that they currently use. These problems were identified in discussions with the operators of the terrain data base generation systems described in Section 2. Section 3.2 discusses several other issues and their impacts on the synthetic environment terrain data base generation process, such as the concepts of scale and level of detail, the use of cartographic sources in the production of DTD, and the constraints imposed by real-time image generators. Wherever possible, requirements are stated for DTD products that are to be used in synthetic environment terrain data base generation.

3.1 PROBLEMS WITH EXISTING DTD SOURCES

NIMA standard digital topographic data products, such as DTED, DFAD, and ITD, are the primary inputs to the synthetic environment terrain data base generation process. However, the current NIMA DTD products have a number of characteristics, because of the requirements which they were produced to address, and the manner in which they were produced, that are not fully compatible with the needs of this process. Synthetic environment terrain data base generation processes would be much more effective and efficient, producing better products much more rapidly, if these characteristics could be modified in future DTD products intended for use by the modeling and simulation community. In approximate order of importance, these problems are:

- Lack of availability at the necessary levels of detail

- Lack of consistency, including geometry, feature classifications, attribute values, and feature connectivity

- Lack of integration between terrain elevation and feature data

- Lack of integration of feature data in multiple thematic coverages

- Lack of completeness, with respect to features, attributes, and relationships.

Each of these problems is discussed as follows:

Surprisingly, perhaps, the level of detail of the existing standard DTD products is not currently a problem, except in the sense that the availability of these products is not adequate. In general, "Level 1" DTD products currently provide an adequate level of detail for synthetic environment terrain data bases that are used to support aircraft and helicopter simulators, except

in those relatively limited areas, such as airfields, navigation waypoints, and target areas, where the aircraft operate very close to the ground, therefore greater detail is required. Similarly, "Level 2" DTD products currently provide an adequate level of detail for synthetic environment terrain data bases that support ground vehicle simulators. However, future applications of virtual and "live" simulation, such as those supporting dismounted infantry and Military Operations in Built-up Areas (MOBA), may require even greater levels of detail (i.e. "Level 3" or "Level 4" DTD products).

It is important to note that these statements of adequacy are not based on the level of detail requirements of the applications for which the simulators are being used, such as training or mission rehearsal, but rather on the current capabilities of the image generation systems that are used to display the contents of the data bases in real-time, as out-the-window visual, radar, or infrared views. Currently, in fact, much of the information contained in the existing "Level 2" DTD products is discarded, through elevation grid resampling and optimization, TIN generation, and feature thinning and generalization operations, in order to meet the real-time performance constraints of the image generators. These constraints are related to feature density, rather than resolution, as too many features in a particular area result in more polygons than the image generator can display in real time. As a result, the "less significant" features are removed, and the remaining features are generalized and snapped to the terrain grid to reduce the number of polygons that they generate. This does not mean that these features are not needed, but that the current image generator hardware cannot support their use. The rapid advances in real-time computer graphics technology that have been occurring in recent years, and which can be expected to continue, will continue to reduce the impact of these constraints, at least for new systems. Unfortunately, this means that the optimal feature density for synthetic environment terrain data base generation will continue to be a rapidly moving target that can be expected to eventually reach the feature density of the current "Level 2" DTD products.

3.1.1 DATA AVAILABILITY

The lack of availability of standard DTD products for specific geographic areas, at the necessary level of detail to support ground vehicle simulation, is the single greatest and most difficult problem that synthetic environment data base builders must face, and can be expected to remain so for many years to come. The lack of available DTD forces data base developers to use a wide variety of alternative sources, including many different types of imagery and cartographic sources, in both hardcopy and digital form. This greatly complicates the front end of the synthetic environment data base generation process and limits the quality and fidelity of the resulting data bases.

Synthetic environment terrain data base generation processes are currently designed to use standard DTD products, DTED (Level 1 or 2), DFAD or ITD, as their primary sources of terrain information. When a data base must be created for an area for which these sources are not available, other sources must be used, and a great deal of additional work must be performed. Essentially, when standard DTD products are not available, a synthetic environment terrain data

base generation system must attempt to emulate the NIMA production process for those products, using whatever sources can be obtained. This emulation is typically quite crude, in comparison with NIMA's production processes, and the quality of the results are necessarily limited. This involves the extraction of features, currently done manually, from digital imagery or raster maps, or the manual digitizing of hardcopy imagery or maps. In some cases, hardcopy sources are scanned and transformed to create controlled digital raster sources, but this also is a time-consuming and error-prone operation. The generation of terrain elevation information, when DTED is not available, is particularly difficult, and is not attempted by most existing synthetic environment data base generation systems.

Requirement: Synthetic environment applications involving the simulation of ground vehicles will require "world-wide" DTD coverage at "Level 2" resolution (i.e., 1:50,000-scale equivalent).

The near-term availability of NIMA's CIB product, in Raster Product Format (RPF), will help to address this problem to some degree, by providing a standard source of controlled, 10-m resolution imagery with worldwide coverage. Once CIB is available on a worldwide basis, terrain data base generation systems should no longer have to be concerned with as wide a variety of imagery sources. CIB also is very useful in resolving ambiguities in DTD, such as in determining the actual configurations of highway interchanges. The Digital Point Positioning Data Base (DPPDB), when available over the area of interest, will provide an even better source for analysis, as well as a supplementary source for feature elevation data extraction.

NIMA's forthcoming VMap series of products also will help to address this problem, but in a more limited manner. The VMap products will provide a new DTD source for synthetic environment terrain data base generation systems, however these products are being produced from existing cartographic sources, therefore so will be of much more limited accuracy and currency. Also, they will only provide 2-D feature coordinates, not integrated with the terrain surface. VMap Level 0 (1:1,000,000-scale equivalent) is too coarse to be useful for synthetic environment applications, except perhaps as distant background areas for high-flying aircraft. VMap Level 1 (1:250,000-scale equivalent) should be available for all areas covered by JOGs by the end of FY2000, and will be useful in creating synthetic environment terrain data bases for aircraft simulation applications when no better sources are available. VMap Level 2 (1:50,000-scale equivalent), created from 1:50,000- and 1:100,000-scale Tactical Line Maps (TLMs) also will begin to become available starting in FY96, and will be useful for creating synthetic environment terrain data bases for ground vehicle simulation applications, again, when no better sources are available.

When both CIB and VMap Level 2 are available for a particular location, terrain data base developers will face a tradeoff. CIB will potentially provide a higher quality result, but will have to be converted into DTD in order to be used. VMap Level 2 will provide quicker results, but of lower quality. In the long term, a "Level 2" DTD product produced from imagery sources, such as TTD, will be necessary to meet the requirements of ground vehicle training and mission

rehearsal applications. However, until there are significant advances in automated or semi-automated feature extraction, the low rate of TTD production, because of its labor intensive nature, will prevent it from being available in significant quantities for many years to come. By that time both remote sensing technology and application requirements will have changed drastically. Meanwhile, users will have to be able to deal with VITD, VMap Level 2, or TTD/DTOP, depending on which of these products, if any, is available for their area of interest.

3.1.2 DATA CONSISTENCY

Another significant problem with current DTD products is their lack of consistency, both internal within each individual dataset, and across datasets that are adjacent or near one another. There are many variations of this problem, a few of which include:

- Poorly formed features or other geometric anomalies, such as roads or streams that contain small loops or small disconnected segments (possibly representing highway on/off ramps, etc.)

- Elevation values which do not match across cell boundaries

- Elevation anomalies, such as spikes, pits, or "corn rows"

- Features which do not connect properly at, or across, cell or manuscript boundaries, because the corresponding feature is either missing, misaligned, or misclassified

- Feature classifications which are not consistent, such as a highway which changes to a cart track when it crosses a cell or manuscript boundary

- Attribute values which are not consistent, such as a highway which changes from asphalt to concrete when it crosses a cell or manuscript boundary

- Problems in the integrity of transportation and drainage networks, such as missing or disconnected segments.

Terrain data base developers currently must spend a great deal of time and effort thinning and editing digital topographic data to correct or remove such problems. Improvements in these aspects of the quality of standard DTD products can therefore make the data base generation process much easier, and also improve the quality of the resulting data bases.

Requirement: Synthetic environment applications require DTD which is consistent, seamless, and free of anomalies.

New NIMA DTD products, produced using NIMA's Digital Production System (DPS), which includes many new quality control mechanisms, promises to be of much higher quality than

the older products currently in use, eliminating the more common types of anomalies, such as inconsistencies across manuscript and cell boundaries. However, synthetic environment terrain data base developers will continue to have to deal with the older DTD products until they are completely replaced by new production.

Network Integrity

Another specific type of consistency problem arises when feature networks, such as transportation or drainage networks, are thinned to meet the real-time performance constraints of image generators. It is common practice for such networks to be thinned, either by eliminating all of the segments with a specified feature code (e.g. cart tracks), or by eliminating segments based on some attribute value (e.g. stream width) or combination of attribute values. However, such operations often damage the integrity of the network, dropping out a particular segment while the adjacent segments remain, thus, destroying the network structure. Also, the attributes that may work well for thinning a road network in one part of the world may not be applicable in another. Networks also are commonly thinned by eliminating those segments which are "dead ends" of the network, such as minor road segments or the smallest streams. However, this must often be accomplished by a tedious manual process, selecting each segment individually to be eliminated.

Requirement: All features which are part of a network (transportation, drainage, etc.) must include an attribute identifying the level of significance of that feature within the network, such that all features with significance levels below a specified threshold can be removed without destroying the overall integrity of the network.

What is needed to alleviate this problem is an attribute associated with network segments that reflects the "degree of significance" of the segment in maintaining the overall structure of the network. This would allow feature networks to be thinned more easily by specifying the elimination of all segments below a certain threshold of significance. The FACC Transportation Use Category (TUC) attribute provides this kind of information for transportation networks, but not in a form that allows a significance threshold to be easily used for thinning.

3.1.3 INTEGRATION OF TERRAIN ELEVATION AND FEATURE DATA

DTED, which is the primary source of terrain elevation information used in synthetic environment terrain data base generation, and DFAD, or ITD, which are the primary sources of terrain feature information, are generally not very well correlated with each other. DTED and DFAD, and more recently, ITD, have been produced by two completely separate processes, in some cases using separate data sources. Therefore, it is not surprising that problems arise when these two separate, independently created DTD products are combined to create a 3-D representation of the terrain. One result of this is that the slope information contained in ITD is not used by synthetic environment terrain data base developers, because it is not consistent with the terrain surface created from the corresponding DTED.

Simply combining DFAD or ITD with DTED is analogous to creating a 3-D plastic relief map by projecting a flat map onto a molded plastic surface representing the terrain. The 2-D feature data is simply draped over the 3-D terrain surface. For high-flying aircraft simulations this may be adequate, since terrain features are only seen from above, and at relatively large distances. However, ground vehicle simulation applications are not so forgiving.

To support ground vehicle simulation applications, roads and other features must be correlated properly with the terrain surface so that vehicles can drive along the roads, and across the terrain, properly. Roads must not have unreasonable pitch or roll angles, so that simulated vehicles can drive along them. Similarly, rivers and streams should not flow uphill. The surfaces of bodies of water, such as rivers and lakes, should have a constant elevation.

The types of anomalies that can result from lack of correlation between terrain surface and feature data vary widely by feature type. Many types of visual anomalies that result from this problem do not necessarily interfere with the use of a terrain data base for training or even mission rehearsal purposes. It may not be cost effective to correct such anomalies in large data bases, particularly if they are being constructed under tight time constraints. It may even be argued that such anomalies are useful in that they remind the vehicle crews that the synthetic environment has limited fidelity relative to the real world.

However, some types of anomalies resulting from the lack of correlation of elevation and feature data can significantly interfere with the effectiveness of training or mission rehearsal, either by preventing necessary actions from being carried out, or by being so distracting to the vehicle crews that the value of the simulation is lost. Such anomalies must be corrected or otherwise eliminated from the data base.

Currently, data base developers spend significant time and effort attempting to correct or eliminate such anomalies, using a combination of automated and manual techniques. When TINs are used to represent the terrain surface, transportation and drainage features can be integrated into the TIN surface as additional polygons. When regular grids are used to represent the terrain surface, cut and fill techniques are used, either fracturing the terrain polygons to create cuts, or building raised road or railroad beds on top of the terrain polygons to create fills. Research on feature integration techniques is continuing.

Requirement: Synthetic environment applications require 3-D digital terrain elevation and feature data, which is produced from the same source material with the same level of accuracy, and is fully correlated.

The simplest solution to this problem would be for NIMA to produce a single integrated DTD product combining both elevation and 3-D feature information. A single, integrated product containing spot elevations (regularly spaced or not), and geomorphic features (peaks, ridgelines, etc.), as well as 3-D representations of all other tactically significant natural and cultural features, would simplify the creation of synthetic environment terrain data bases and improve their fidelity.

The geomorphic features add critical information to the regular grid of elevation posts, since they define extreme points of elevation and relate them to one another. However, all 3-D feature coordinates, if they represent independent measurements of the terrain surface, can add important information to the terrain surface. For example, rather than estimating where road cuts and fills need to be located, these characteristics could be identified by the relative elevation of the road compared with the surrounding terrain. For this to be effective in improving the overall fidelity of the terrain surface, however, the relative accuracy of both elevation posts and 3-D feature points is very important.

All of the independent measurements of the terrain surface, including both elevation posts and 3-D feature points, could be integrated into a single TIN representing a baseline terrain surface which incorporates all of the measured data. The relationships among the feature points, such as the sequence of points making up a road segment, also can be incorporated into the TIN as constraints, that is, required edges within the triangulation. Such a representation could then be used to evaluate the fidelity of other terrain surface representations, including regular grids, multilevel grids, and TINs, which use only a subset of the measurements in order to meet image generator constraints.

It should be possible to represent such an integrated product using NIMA's VPF with a few relatively minor extensions. NIMA's DPS is capable of producing both terrain elevation and 3-D terrain feature information from the same stereo imagery source, with much better accuracy than older DTD products.

DPS automatically generates a variable resolution grid of elevation posts, typically with 1.5 arc second spacing (.375 and .75 arc second spacings also are possible). These points usually lie on the terrain surface, within a small error tolerance, but in some cases, such as in forested or urban areas, they may be above the actual ground surface. When features are digitized, coordinates for most feature types are normally measured by the operator at the terrain surface, as defined by the stereo imagery. Thus, these feature coordinates provide additional, independent measurements of the terrain surface which can be used to enhance its representation. This is true not only for geomorphic features, such as peaks, ridge lines, and valleys, but also for features such as roads and streams. For some types of features, however, the measurements are made above the ground surface. For example, buildings are normally digitized at the roofline. Towers may be digitized at their highest point, or at their point of greatest horizontal extent. These measurements also can be used to help define the terrain surface if appropriate adjustments can be made to estimate the heights of these features.

Feature coordinate elevations also can be automatically generated by interpolating from the elevation grid. If this option is used, however, the feature coordinates do not represent independent measurements of the terrain surface. Fortunately, this interpolation method is not commonly used, as it tends to result in more inconsistencies, such as streams that flow uphill, that must be caught and corrected later in the process.

This process, which will be used in producing DTOP, has the potential to provide an integrated source of elevation and feature data, with all vertices representing 3-D coordinate measurements taken directly from the stereo imagery. Such a product could greatly facilitate the synthetic environment terrain data base generation process. However, there would initially be substantial obstacles to the exploitation of such an integrated 3-D product. Existing tools would not be able to process such a product without significant modifications. Fortunately, these modifications could easily be combined with the modifications that will be necessary to support the exploitation of 3-D VPF-based products, such as TTD/DTOP.

Location of 3-D Coordinate Points

Synthetic environment terrain data base developers generally assume that all feature points are located on the terrain surface. This is true by definition for the 2-D feature points currently used to create synthetic environment terrain data bases. When synthetic environment terrain data base developers begin to use new DTD products with 3-D coordinates, they will naturally continue to make this assumption. When a 3-D model is used to represent a point feature, the given coordinates will be assumed to be at the base of the feature. Similarly, when line-of-sight calculations are performed, it is virtually always assumed that the elevation posts indicate the location of the terrain surface, and that the height of any vegetation features should be added. However, as noted above, this assumption is not always a good one, as elevation posts may be located above the ground in forested or urban areas, and some types of features are collected at points above ground level. Either ALL points reported should be at ground level, or, DTD users must be made aware whenever this is not the case.

Requirement: DTD products to be used for synthetic environment terrain data base generation must report all 3-D coordinate locations at the terrain surface, or must clearly indicate the relative height of each location above or below the terrain surface.

3.1.4 INTEGRATION OF MULTIPLE FEATURE COVERAGES

All of the current DTD products which are used as primary sources of feature data for synthetic environment terrain data base generation, and all of the planned DTD products which may fill this role in the future, organize feature data into multiple thematic layers. DFAD prioritizes individual point, line, and area features according to which features should be displayed on top of other features, effectively giving each feature its own layer. ITD is organized into six layers, corresponding to the six transparent tactical terrain analysis overlays for hardcopy 1:50,000 TLMs from which it is derived. In some cases, the ITD layers are produced separately by different operators, which can result in serious correlation problems. The forthcoming VPF-based products, including VITD, VMap, and TTD/DTOP, all contain multiple thematic coverages.

However, in order to generate visualizations of a synthetic environment, possibly including correlated visual, radar, and infrared sensor views, a single consistent feature layer is needed, with

a high degree of relative accuracy between nearby features. Having features located in different thematic layers, when both must appear in the same view, is neither necessary nor useful. Synthetic environment terrain data base developers currently must use GIS systems and/or other tools to attempt to integrate the layers into a single integrated representation.

Even when the multiple thematic coverages of a standard DTD product are initially correlated, independent processing of the individual layers, including feature thinning, generalization, editing, and other operations can easily create correlation problems, as the path of a feature is altered in one layer, while related nearby features in other layers are not. For example, independently generalizing a stream and a road that parallels the stream can easily produce spurious crossings. When independently processed layers are later combined, a large number of small "splinters" can result.

Requirement: Synthetic environment applications require DTD feature data in an integrated form, with a single topologically consistent layer, and with a high degree of relative accuracy between nearby features.

While VPF is capable of supporting a single integrated feature coverage, all of the VPF products defined to date consist of multiple thematic layers, based on a GIS view of spatial data. In order to create a synthetic environment, these separate thematic layers must be reintegrated to form a single, consistent definition of the synthetic world. A VPF product consisting of a single integrated feature coverage, plus a separate data quality coverage, would make the generation of synthetic environment terrain data bases much simpler. Although the size and complexity of such a product would be much greater than that of existing layered products, the resulting complexity should be acceptable as long as the original data is properly correlated.

Another alternative, much simpler to produce while still simplifying the synthetic environment terrain data base generation process, would be a VPF-based product derived directly from the structure and contents of NIMA's internal MC&G data base, with only a few layers, including elevation, soil/surface material, vegetation, and culture, plus a data quality layer. The elevation layer would have only Level 1 topology, supporting geomorphic features as well as spot elevations derived from the elevation grid. The other feature layers would have Level 3 topology, and would be prioritized, with cultural features overlaying vegetation features, and both overlaying soil/surface material features.

3.1.5 DATA COMPLETENESS

All of the features and attributes needed by synthetic environment terrain data base developers are not included in the current DTD products. For example, ITD does not include powerlines or details of urban areas, and does not provide materials information for all features. Other VPF-based products, such as VMap Level 2 and TTD, will address this problem to some extent. However, it is not clear that the features and attributes contained in these products will fully meet the needs of the synthetic environment terrain data base generation community.

Conversely, there are many features and attributes contained in current products, such as ITD, that are not used by synthetic environment terrain data base generation systems, largely because this information does not lend itself to the automated creation of 3-D representations of the various types of features. For example, the CCTT terrain data base generation process does not make use of the ITD bridge features. ITD does not contain all of the logically necessary bridges in a given area, but only those which have been identified as being of sufficient tactical significance to appear on a TLM. However, the CCTT data base must include a bridge at each location where a road (or railroad) crosses a stream. Therefore, instead of using the ITD bridge features to determine bridge locations, software has been developed to automatically identify all such locations, and inserts one of a predefined set of standard bridge models, based on the stream width, at that location.

Many other feature types, including cuts, fills, and embankments, are deleted from the input dataset as they do not provide complete, integrated information in a form that can easily be used to create 3-D representations of these features at the specified locations. Instead, software has been developed to automatically determine the cut and fill requirements of roads, railroads, and streams, based on maximum positive and negative slope parameters.

This is a fundamental difference between DTD products which are intended to support the creation of 3-D synthetic environments, and previous DTD products, which were created primarily to support symbolic representations of the terrain. This fundamental difference is discussed further in Section 3.2.1.

Requirement: DTD products that are to be used for synthetic environment terrain data base generation must contain sufficient geometric and attribute information to allow all features to be reconstructed as 3-D objects, and to be positioned correctly relative to all adjacent and nearby features.

Each feature, and its attributes contained in a DTD product that is intended to be used for synthetic environment terrain data base generation, should be evaluated relative to this criterion: can a 3-D representation of the feature be created using the geometric and attribute information provided, and can that representation be properly positioned in the synthetic environment relative to all other nearby features? If this is not the case, then additional information is required. For example, if the ends of a bridge cannot be positioned correctly relative to the banks of the stream that it crosses, then additional information is required. Because different features have different types of 3-D representations, and because they may be represented in different ways (i.e., as point, linear, or areal features), the above criteria can only be stated in general terms. Each feature needs to be investigated and evaluated individually.

Multiple Elevations

Current DTD products do not provide adequate information at points where multiple significant elevations exist. This is primarily a concern with respect to bridges, overpasses,

interchanges, and tunnels. At many of these locations the information provided about the connectivity of the features is not sufficient to construct a realistic 3-D representation. While it can be generally assumed that roads and railroads cross over streams at bridges, making similar assumptions about the behavior of roads and/or railroads at overpasses and interchanges is not feasible. The CCTT terrain data base generation process replaces all such intersections of linear features with custom, automatically generated, 3-D models, using auxiliary sources of information, such as site surveys or imagery, to determine the connectivity and stacking behavior of the individual features. CIB will be useful in resolving some of these ambiguities, as the imagery can be consulted to determine just how the features interact with each other at such locations.

Requirement: DTD products to be used for synthetic environment terrain data base generation must be capable of reporting multiple significant elevations at the same location, such as at bridges and overpasses, and must represent the true connectivity of the features that meet at (or pass through) such locations.

The data structures provided by VPF are capable of supporting multiple nodes with the same horizontal position, but with different elevations. It also is possible to construct tunnels using VPF data structures as actual holes in the terrain surface. However, these structures significantly stretch, if not violate, the assumptions of planar topology, and it is not clear that such structures can easily be generated by NIMA's current production processes.

Surface Materials

Current users of DFAD, particularly DFAD which generates radar and/or infrared views of the synthetic environment, rely heavily on the DFAD Surface Material Category (SMC) attribute, the name of which has been changed to Radar Significance Factor (RSF) in the most recent revision of the DFAD product specification. Although the FACC being used in all VPF products includes a SMC, as well as several other similar attributes such as Material Composition Category (MCC), Material Composition Secondary (MCS), Material Composition Underlying (MCU), Bottom Materials Composition (BMC), and Underlying Material Category (UMC), these attributes are not associated with all types of features in a uniform manner that makes it possible to easily determine the material associated with any given location in the terrain data base.

Requirement: DTD products to be used for synthetic environment terrain data base generation must provide complete surface material information for all features.

In order to facilitate the generation of radar and infrared, as well as visual views of a synthetic environment, all faces, all edges with non-zero width, and all nodes with non-zero dimensions, must have an associated material composition attribute. In some cases, perhaps many, the feature code may imply, or at least suggest, a certain material (e.g. a "stream" implies a surface material of "water"), but this is not explicit. Either surface material information should be explicitly added to all features in VPF products that are intended to be used for synthetic

environment terrain data base generation, or the mapping from feature codes to surface materials must be explicitly defined.

3.2 OTHER ISSUES

There are several other significant issues which affect the generation of synthetic environment terrain data bases. These include:

- The differences between traditional cartographic forms of abstraction and the form of abstraction provided by synthetic environments

- The use of cartographic data sources in the generation of synthetic environment terrain data bases

- The importance of metadata in the synthetic environment terrain data base generation process

- The variety of different terrain surface representations used by synthetic environment terrain data base developers

- The impact of full topology in forthcoming VPF products on the synthetic environment terrain data base generation process

- The use of commercial GIS tools in the synthetic environment terrain data base generation process

- The impact of image generator constraints on the synthetic environment terrain data base generation process.

Each of these issues is defined and discussed in the following:

3.2.1 SCALE, LEVEL OF DETAIL, AND ABSTRACTION

The level of detail of traditional cartographic products is characterized by their scale (e.g. 1:50,000). The scale of the cartographic product, or products, that are to be generated, strongly influences the rules used to extract features from imagery sources. Features that are too small to be shown on a hardcopy cartographic product at the target scale are not collected. Small but important features are recorded as points, and rendered as symbols, while long, narrow features are recorded as lines. Features are generalized or adjusted to avoid visual clutter in the final product. Cartographic products are, after all, abstract, symbolic representations of the real world terrain in a particular area that are meant to communicate effectively the relevant characteristics of that terrain to the map user.

Scale, in the traditional cartographic sense, is meaningless for digital topographic data, except when it is being displayed on a particular device or medium, but DTD products are still commonly described in terms of their "equivalent" scale. The data extraction rules for features in NIMA's DPS are driven by a set of products, called a Multi-Product Operations (MPO) group, with relatively similar characteristics and cartographic product scales, all of which are supported by a single extraction scenario. The feature extraction requirements for a particular extraction scenario are determined by the most stringent of the "minimum capture criteria" for that feature across all of the products in the MPO group being supported by that extraction scenario. Similarly, the set of attributes collected for a feature includes all of the attributes required for that feature by any of the products in the MPO group. However, these data extraction rules have been developed primarily to support cartographic symbolization and military geographical analysis, and may not be compatible with the needs of synthetic environment terrain data base developers.

Synthetic environment terrain data bases are primarily used to generate visual (and corresponding radar and infrared sensor) perspective views of the terrain that are, in some sense, viewed at 1:1 scale by the users. These views are constructed from simple three- and four-sided planar polygons. In this polygonal representation, which is created from the DTD vector representation during terrain data base generation, DTD point features are replaced by 3-D polygonal models of the structures which they represent, occupying an areal footprint. Linear features also are expanded into areal features, typically in the form of a collection of polygons. The relationship between the vector and polygonal representations of the terrain is central to the understanding of how synthetic environments are generated. Also, of course, synthetic environments are 3-D.

Currently, many of the features and attributes in standard DTD products are not used in the generation of synthetic environments. In some cases, this is because the abstraction represented by these features and attributes is not compatible with the abstraction represented by synthetic environments. For example, the slope polygon features contained in the ITD Slope/Surface Configuration layer classifies terrain into categories based on an estimation of the slope, expressed as a range of percentages (e.g., 10 percent-20 percent). This abstraction of terrain slope was originally created to support one of the TTADB plastic map overlays, and was intended to allow a tank commander to quickly determine where he should, and should not, attempt to maneuver. Unfortunately, this information is not useful when building a synthetic environment, since it is not consistent with the slope values that can be calculated from the polygonal representation of the terrain surface.

Thus, while a synthetic environment is like a map (an abstraction of the real world), it is clearly not the same type of abstraction that would be used to create a map at a particular scale. It is important to note, however, that these two different types of abstractions do have a common foundation, which is based on the tactical significance of various types of terrain features. The similarities and differences between these two related, but different, types of spatial data abstractions needs to be investigated in more detail.

Multiple Levels of Detail

A traditional cartographic product supports only a single scale, with a corresponding single level of detail. Synthetic environment terrain data bases may support multiple levels of detail in two different senses: one based on the polygonal representation of the terrain, and the other based on the vector representation.

The data bases created to support aircrew mission rehearsal and training typically consist of a low-resolution background covering a very large area, with embedded areas of higher resolution representing planned flight corridors, navigation waypoints, and target areas. The areas represented with lower levels of detail are expected to be viewed only from long distances. Similarly, synthetic environment data bases may explicitly include multiple polygonal representations of objects and terrain features, with the highest level of detail used to render the objects and features closest to the viewpoint, while the lower levels of detail are used to render objects and features at increasingly greater distances. Minimum and maximum viewing ranges are typically specified for each different level of detail, and blending or morphing techniques may be used to avoid abrupt changes in appearance when these thresholds are crossed.

The explicit representation of multiple levels of detail in a synthetic environment terrain data base is done solely to reduce the number of polygons used in displaying distant objects and features, allowing more polygons to be available to display objects and features that are closer to the viewer. Thus, this use of multiple levels of detail is simply an image generator performance optimization. Indeed, some of the more advanced image generators perform this optimization internally, so that only a single (highest) level of detail needs to be explicitly represented in the terrain data base, while others require that multiple representations be explicitly defined along with minimum and maximum viewing ranges for each. In general, polygonal representations with lower levels of detail are generated by simplifying higher levels of detail polygonal representations, whether this is done automatically or manually. Thus, while this is an important issue in the image generator domain, with many implications for simulator interoperability, it is not necessarily an issue which can, or should, be addressed by changes to standard NIMA DTD products.

Currently, the terrain reasoning performed in SAF systems uses a combination of the polygonal representation of the terrain (at the highest level of detail if multiple levels of detail are defined) and the vector representation of the terrain from which the polygonal representation is derived. For ground vehicle simulation applications, this vector representation normally corresponds to "Level 2" DTD products, or a 1:50,000 scale. Conceptually, higher level SAF entities, representing a battalion, regimental, or brigade commander and/or staff, could perform terrain reasoning using a "Level 1" or 1:250,000-scale representation. A division or theater-level command SAF entity could perhaps even use a 1:1,000,000-scale vector representation to perform very abstract terrain reasoning. It is in this sense that multiple levels of detail of the vector representation of terrain might be useful.

No existing or planned standard DTD product contains multiple levels of detail. NIMA's VMap series of products potentially comes the closest, with Level 0 at 1:1,000,000 scale, Level 1 at 1:250,000 scale, and Level 2 at 1:50,000 scale, but currently these products are being produced independently of one another from existing cartographic sources. In the future, when VMap products are produced from imagery sources, it should be possible to derive the lower resolution products from the highest resolution baseline, perhaps in a highly automated manner. It also might be useful to be able to package multiple levels of detail within a single product, i.e., an integrated, multi-level Vmap. When this is done, if not before, unique feature identifiers will be very important, so that representations of the same feature at different levels of detail can be correctly associated with one another.

Minimum Essential Data Sets (MEDS)

Another related concept is that of NIMA's MEDS. This concept was created in an attempt to address the need to efficiently support both rapid generation of critical DTD in a crisis situation, and the generation of very detailed DTD products such as TTD. Features would be prioritized according to their military significance, and grouped into several different MEDS levels. In a crisis situation, data extraction operators would begin working in parallel on the set of cells covering the area of interest, extracting features from the imagery source in priority order. When all of the features corresponding to a MEDS level had been extracted, an interim product would be generated. Meanwhile, the data extraction operators would continue to work their way down the feature priority list, densifying the feature set. Each time a MEDS level was completed, another product would be generated, replacing the earlier product. Finally, the full TTD product would be generated.

The incremental production of MEDS would be difficult for synthetic environment terrain data base systems to deal with. If a synthetic environment terrain data base had been constructed using an earlier MEDS release, there would, in general, be no graceful way of incorporating the new features, particularly those such as roads, drainage, etc., that must be integrated into the terrain surface, into the existing synthetic environment. Therefore, each new MEDS release would trigger a new terrain data base generation effort. However, given that synthetic environment terrain data base generation systems currently do not use much of the data contained in ITD datasets, it may be the case that one of the TTD/MEDS levels would actually be more suitable for synthetic environment terrain data base generation than the full TTD product. This possibility needs to be investigated in more detail by examining the contents of each of the proposed TTD/MEDS levels, and, perhaps, constructing synthetic environment terrain data bases using source data corresponding to each of the MEDS levels.

3.2.2 USE OF CARTOGRAPHIC SOURCES

DTD is currently generated from both imagery and cartographic sources (i.e., existing maps). DTD generated from imagery sources is more accurate, more complete, and more current. Also, DTD extracted from stereo imagery has the potential to combine 3-D elevation

and feature information in a single integrated form. However, the extraction of DTD from imagery sources is still very time consuming and labor intensive. It is primarily for this reason that the available coverage of high resolution DTD products, such as TTD, will be limited for years to come.

DTD can be generated rapidly using existing cartographic sources since all of the necessary terrain analysis was accomplished when the source map was created. However, DTD generated from cartographic sources can have very limited accuracy and may be badly out of date. Also, detailed metadata for the resulting DTD product may be difficult or impossible to create, since the existing cartographic source may not provide the necessary information.

The VMap series of DTD products is initially being produced from cartographic sources. This is being done in an attempt to address the DTD availability problem identified in Section 3.1.1, which affects not just synthetic environment terrain data base generation, but all Army uses of digital topographic data. In the short run (1-5 years), the choice will be between DTD from cartographic sources, with good availability but limited quality, and DTD from imagery sources, with good quality but very limited availability. In the longer term, advances in feature extraction technology should help to change the current tradeoff between data availability and data quality, so that high quality DTD can be produced from imagery sources easily, and cartographic sources will no longer need to be used.

While DTD products such as Vmap, which are derived from cartographic sources, will be used in the generation of synthetic environment terrain data bases, such sources should only be used when there is no better alternative available. Also, when synthetic environment data bases are generated from such sources, this fact should be clearly stated in the metadata associated with the resulting data bases so that users are made aware of the level of quality and fidelity that the data base represents.

3.2.3 METADATA

Metadata is data that describes the content and meaning of the spatial data contained in a data base, and includes identification, security, and data quality information that specifies the lineage, accuracy (positional and attribute), consistency, and completeness of the data. Metadata also may be considered to include any data dictionary information included in the data base. While all of the new NIMA DTD products generated from imagery sources contain extensive, comprehensive metadata, the metadata contained in older DTD products, and in DTD products generated from cartographic sources, tends to be much more limited.

The SSDB SIF also provides for fairly extensive metadata, but most other synthetic environment data base formats, such as S1000™, MultiGen® OpenFlight™, and the internal data bases used by terrain data base generation systems, contain little or no metadata. Not only do they not produce metadata which describes how they have modified the source data that they use, but they do not even maintain the metadata that was provided by the source. As a result, the level of

fidelity of most existing synthetic environment data bases is completely unknown. This will be a serious problem if these terrain data base generation systems are to evolve toward becoming DTD co-production facilities for NIMA standard products, or if synthetic environments are to be used for mission rehearsal where the level of fidelity must be known with some level of confidence.

3.2.4 TERRAIN SURFACE REPRESENTATIONS

Currently, a variety of different representations are used for the terrain surface, ranging from regular arrays of right triangles based on a matrix of elevation posts, to multi-level grids in which right triangle sizes are adjusted based on local terrain roughness criteria, to TINs. All of these representations are strongly influenced by the polygon budget limitations of the image generators with which they will be used. Because of the irregular nature of the real world (coastlines, rivers, mountains, etc.), regular representations of the terrain surface tend to quickly become more and more artificial, and less and less efficient, as the resolution of the data base increases. The growing use of TINs reflects this. However, there is currently no indication that standard methods of creating, generalizing, or representing TINs will be adopted in the near future by the synthetic environment terrain data base development community.

Regular grids were used in the early SIMNET terrain data bases, which were created using the S1000™ data base generation toolset. Typically, a DTED Level 1 grid, with 3-arc-second spacing between elevation posts, was resampled and projected to create a flat-earth elevation grid in local Cartesian coordinates with 125-meter spacing. Each grid cell was then divided into 2 125-m right triangles. Each 500-m square load module, the basic organizational unit of an S1000™ data base, would therefore contain 32 terrain triangles. Similarly, the SOF ATS data base generation system uses a DTED Level 2 grid, with 1-arc second spacing, which is output directly to an ESIG-4000 image generator.

While a regular grid was sufficient for the initial SIMNET data bases, the limitations of a regular grid representation of the terrain surface began to become obvious as soon as a data base was constructed that included a coastline. The SAKI data base modeled the coastline as a linear feature, and replaced the right triangles along the coastline with irregular "microterrain" triangles connecting the coastline vertices with the closest inland elevation posts. The inclusion of major rivers and other such irregular features caused the use of this "microterrain" technique to increase.

In order to provide a higher resolution terrain surface, while still minimizing the number of terrain surface polygons, the CCTT primary terrain data bases use a multilevel grid structure. The CCTT terrain data bases are organized into 960-m square modules. Initially, a DTED Level 2 elevation matrix is projected and resampled to create a Cartesian coordinate grid with 30-m spacing between elevation posts. Each 30-m cell is then divided into 2 right triangles. The terrain surface is then "optimized" by replacing groups of 8 30-m triangles, covering a 60-m square area, with 2 60-m triangles, provided that all of the eliminated elevation posts fall within a specified distance of the resulting surface. This process can be applied repeatedly, resulting in triangles that are 120 m, 240 m, 480 m, or 960 m in size. The distance parameters used to control the process

are derived using two different terrain roughness metrics. In general, the parameters used for rougher areas of the data base are "looser," allowing for more terrain surface relaxation in these areas. This gives up detail in the areas of rough terrain where vehicles are unlikely to enter, while retaining as much detail as possible in the flattest, smoothest areas, where every bit of terrain cover is significant. Features, including roads, railroads, and streams, are then integrated into the terrain surface by a combination of cutting and filling, based on maximum slope parameters for each type of linear feature.

TINs have become increasingly popular for representing the terrain surface in synthetic environment data bases. Currently, most TINs are created from regular grids of elevation posts, starting with a minimal set of vertices corresponding to a coarse subsampling of the original elevation posts. Additional vertices are then added incrementally, until an accuracy criteria is met, defined in terms of the distance between the TIN surface and the surface defined by the original elevation grid. This criteria can be varied in different areas of the data base based on terrain roughness metrics. Image generator polygon density constraints also are used as TIN generation stopping criteria. Module boundaries are often incorporated into the initial TIN structure, with, as a minimum, all module corners automatically included as TIN vertices. Alternatively, an initial TIN surface can be generated using all of the available elevation points, and then this surface can be relaxed by incrementally removing vertices. Because many different methods are currently used to generate TINs, TINs generated for the same area, based on the same elevation matrix, can be significantly different in structure. Features, including roads and streams, are sometimes integrated into the TIN surface. Lakes and other such bodies of water, as well as road intersections, are typically "flattened."

Given a collection of 3-D coordinates representing direct measurements taken from a stereo imagery source, it should be possible to create a "baseline" TIN which would serve as a standard against which all other terrain surface representations, which use, at best, a subset of these measurements, could be compared. The edges which define features, especially geomorphic features such as peaks and ridge lines, can be included in the TIN as constraints, so that all area features correspond to collections of terrain surface facets, all linear features run along terrain surface facet boundaries, and all point features, including spot elevations corresponding to the gridded elevation posts, are terrain surface facet vertices. Even if such a TIN is not explicitly constructed, the collection of original 3-D coordinate points should be used in evaluating the fidelity of all other derived surface representations, either regular or irregular.

3.2.5 IMPACT OF FULL TOPOLOGY

Older DTD sources, such as DFAD, contained no topological information. ITD contains Level 1 topology, where segments are connected at nodes. The new VPF-based products, including VITD, the VMap series, and DTOP, can contain one of four levels of topology in each individual coverage layer. Most coverages in these products contain full, or Level 3, topology. Topological relationship information is very important to SAF systems that model the movements and other activities of ground vehicles with the direction of human crews. These systems must

perform terrain reasoning operations at both the direct (polygonal) and symbolic (vector) levels. However, it is important to note that since SAF Data Base developers have not had full topological information available in the past, they are just beginning to develop algorithms that exploit such information. This is discussed further in Section 4.

Current synthetic environment terrain data base generation systems were created to use sources that contained, at most, limited topological information (e.g. transportation and drainage networks). Also, the image generators which have been the primary drivers of the development of these systems do not require topological information. As sources of feature data that contain full topology become available, these existing systems will have to change significantly to maintain the integrity of the topology during all feature thinning, generalization, editing, and integration operations, and ensure that the topological information is successfully passed on to the SAF Data Bases. For those systems that heavily rely on commercial GIS software for such operations, such as ARC/INFO, this should not be a problem. For those that use custom-developed software for feature manipulation, however, this may require large-scale software redesign.

3.2.6 ROLE OF GIS

The synthetic environment terrain data base generation processes described in Section 2 use commercial GIS systems, specifically ARC/INFO, to varying degrees. Typically, the GIS is used for filtering, thinning, generalizing, buffering, integrating, and editing features. The TEC DPC terrain data base generation process makes significant and explicit use of ARC/INFO as a front end to the S1000™ data base generation toolkit. The SOF ATS also makes extensive use of ARC/INFO, but it is hidden beneath a custom user interface that makes it appear to be a seamless component of the terrain data base generation system. In the CCTT terrain data base generation process, ARC/INFO is used to a more limited extent as an adjunct to the EaSIEST toolkit, while in the MTSS terrain data base generation process, no commercial GIS is used.

Those systems which do not use a commercial GIS contain software that performs at least some typical GIS functions, such as thinning, generalization, and editing. The EaSIEST toolkit around which the CCTT terrain data base generation process is built includes both thinning and editing capabilities. The TARGET software used in the MTSS terrain data base generation process also provides many typical GIS functions, but within a more specialized environment.

Terrain data base generation systems which make use of commercial GIS software should be more easily adaptable to changes in DTD standards and products, as the GIS software should evolve to take these changes into account. Conversely, systems which use custom software will be heavily impacted by such changes, such as the arrival of VPF-based products in the near future. On the other hand, the functionality that these custom systems provide may be better suited to the specific requirements of the development of synthetic environments. Also, commercial GIS systems may be slow to adapt to the special needs of synthetic environment terrain data base developers, at least until synthetic environment terrain data base developers become a significant percentage of the commercial GIS customer base. For example, ARC/INFO does not currently

provide adequate support for 3-D coordinates, or for the integration of terrain elevation and feature data.

3.2.7 IMAGE GENERATOR CONSTRAINTS

Currently, image generator constraints influence nearly all aspects of the synthetic environment terrain data base generation process. DTD sources are severely thinned and generalized to reduce the number of polygons that will result from features. When imagery or cartographic sources are digitized, polygon budget constraints are the primary factor used to determine which features are included. The module boundaries of the run-time data bases also are considered very early in the process. These elevation matrices are resampled according to load module size and positioning, feature vertices, and/or TIN vertices, and are "snapped" to module edges and corners, again to reduce the number of polygons that will result. Thus, in very fundamental ways, image generator constraints and performance parameters strongly influence the fidelity of the resulting synthetic environment terrain data base.

There are several different types of constraints that may be derived from the performance limitations of a particular model or "family" of image generators, including:

- Overall Data Base Storage Size—For example, the original SIMNET image generators have a limit on overall data base storage size of 50 MB. This tends to severely limit the geographic extent of the data bases that can be used with these systems

- Polygon Density—This type of constraint can be defined at global, neighborhood, and/or local levels within a terrain data base:

  — At the local level, a polygon density constraint is usually expressed in terms of an absolute maximum number of polygons permitted in a single module, derived from a maximum module storage size. No single module in the data base can exceed this maximum. This also tends to limit the geographic size of individual modules, making module boundaries more numerous, thus, breaking up the "natural" terrain polygons to a greater extent.

  — At the neighborhood level, the constraint is usually expressed in terms of the maximum number of polygons in an N by N module region, or equivalently, as the maximum average number of polygons per module within such as region. The neighborhood region corresponds to the field of view from a particular viewpoint, out to some defined maximum range. For example, S1000™ Data Bases include a constraint on the number of polygons in any region consisting of

an 8 by 8 array of modules, representing a 90 degree field of view out to approximately 4 km.

— At the global level, the constraint is usually expressed as a maximum average number of polygons per module, where the average is computed across the entire data base.

• 3-D Model and/or Texture Library Size—Image generators may have a limited amount of memory available to store 3-D models and/or geotypical or geospecific texture patterns. This limits the variety of features that can be depicted in a data base.

Because the run-time image generator constraints have such a strong influence on the process, synthetic environment terrain data base generation processes tend to be oriented toward one particular type, or "family" of image generators. For example, the S1000™ data base generation tools are organized to supply data for the image generator types used in the original SIMNET simulators. Similarly, the EaSIEST toolkit used in the CCTT terrain data base generation process is aimed at producing data bases for the ESIG-3000 image generators used by the CCTT program, and the TARGET Data Base generation tools are aimed at producing data bases for use with the CompuScene series of image generators, as well as other GE Aerospace/ Martin Marietta/Lockheed Martin image generators.

The need to produce a single data base that can be used with a variety of different image generators inevitably leads to a "least common denominator" approach to data base generation, where the content of the data base is limited in order to meet the constraints of the least capable of the target image generators.

It should be noted that the performance of image generators, and of 3-D graphics systems in general, can be expected to continue to improve dramatically in the near future. Only a few years ago the systems currently in use would not have been possible. SGI, for example, states that it plans to double the performance of its 3-D graphics systems each year for the next ten years, resulting in a thousand-fold increase in performance by 2005. The constraints of current image generators, therefore, cannot be allowed to restrict the development of synthetic environment terrain data bases with higher polygon densities, thus, greater levels of fidelity.

4. SYNTHETIC ENVIRONMENT TERRAIN DATA REQUIREMENTS FRAMEWORK

Synthetic environment terrain data base users can be classified according to the domain within which they operate, and the type of system being supported. Domains include aircraft simulations (fixed wing and helicopters), ground vehicle simulations, and dismounted infantry simulations. Our focus here is on ground vehicle simulations. The three primary types of ground vehicle simulation systems that use synthetic environment terrain data bases are:

1. "Live" Simulations, which use actual vehicles, and which interact with terrain in the following ways:

    - Sensors, which allow the crew to observe various aspects of the actual terrain, including:

        — Visual (Out-the-Window)

        — Infrared/Night Vision

        — Radar

    - Movement, which involves the actual vehicle moving across the terrain

    - Terrain Reasoning, performed by the vehicle crew, and including two levels:

        — Direct terrain reasoning, based on the crew's direct view of the actual terrain

        — Symbolic terrain reasoning, using hardcopy maps or electronic map displays (i.e., DTD) to reason about those parts of the terrain that are not in direct view.

2. Manned Simulators, with live crews inside physical mockups of vehicles that may interact with terrain in the following ways:

    - Image Generators, which dynamically create synthetic views of the simulated terrain for the crew, representing the outputs of various types of sensors, including:

        — Visual (Out-The-Window)

        — Infrared/Night Vision

— Radar

• Movement Simulation, which dynamically models the movement of the simulated vehicle over the simulated terrain

• Terrain Reasoning, performed by the simulator crew, and including two levels:

— Direct terrain reasoning, based on the crew's view of the output of the image generators

— Symbolic terrain reasoning, using hardcopy maps or electronic map displays (i.e., DTD) to reason about those parts of the terrain that are not in direct view.

3. CGF, also known as SAF, are completely simulated in software, including the crews, and may interact with terrain in the following ways:

• Sensor Simulation, which dynamically determines which elements and attributes of the simulated terrain can be observed by the crew using various types of sensors, including:

— Visual (Out-The-Window)

— Infrared/Night Vision

— Radar

• Movement Simulation, which dynamically models the movement of the simulated vehicle over the simulated terrain

• Terrain Reasoning, which models the terrain-related analysis and decision-making of the simulated crew, and is performed at two levels:

— Direct terrain reasoning, modeling the terrain-related reasoning of the simulated crew concerning those elements of the terrain that can be directly viewed, using the outputs of the sensor simulators

— Symbolic terrain reasoning, modeling the terrain-related reasoning of the simulated crew concerning those elements of the terrain which are not in direct view, using hardcopy maps or DTD.

The above categories of simulation operations that use terrain data can be used as a framework for organizing the DTD requirements of synthetic environment terrain data bases.

As these descriptions demonstrate, all three of these types of systems perform the same kinds of operations using terrain data, however they perform them in different ways because of differences in their hardware implementations, and the presence or absence of a live vehicle crew. Ideally, all of the ground vehicles in a networked simulation should require, and use, exactly the same terrain data, regardless of whether the simulation is being executed using a live vehicle, a manned simulator, or a SAF system. However, in practice, the data requirements of these different types of simulations are somewhat different, primarily because of performance considerations. Manned simulator systems are primarily concerned with the generation of realistic real-time out-the-window (OTW) imagery for one or more viewpoints associated with a single vehicle. Typically, the same data base is used to support visual IR, and sometimes radar displays, using different attributes of the same polygonal representation of the environment. A mobility data base also may be needed by a ground vehicle simulator to ensure that the movement of the simulated vehicle over the terrain is realistic.

SAF systems, on the other hand, are concerned with simulating relatively large numbers of vehicles simultaneously, including, at least to some degree, simulating the behavior of the crews of those vehicles. The goal is to achieve sufficiently realistic behavior, for as many vehicles as possible, while maintaining real-time operation. Thus, just as the image generator run-time data bases are driven by the constraints of real-time computer graphics, the SAF run-time data bases are driven by the constraint of real-time simulation performance. The levels of abstraction of the models used in a SAF system, including sensor models, mobility models, etc., are determined primarily by this constraint, which, like real-time graphics performance, is a rapidly moving target.

It should be noted that in all of the synthetic environment terrain DBGSs examined, the visual image generator run-time data base was the primary product of the process, and drove the data base requirements and design. SAF data bases, when they are produced, are almost a by-product of the terrain data base generation process. This means that existing SAF data bases do not reflect SAF requirements in any true sense.

The types of terrain reasoning performed in SAF systems can be considered to consist of two different levels. One level, which uses the polygonal representation of the crew as well as any night vision equipment or other IR or radar sensors. The polygonal representation also is used to support the real-time decision making of the commander and driver of the vehicle. A vector representation of the environment is sometimes needed by SAF systems, however. This representation supports a higher level of terrain reasoning, analogous to the vehicle commander looking at his map, or its electronic equivalent, and makes planning decisions concerning movement routes, fields of view and fields of fire, cover and concealment, etc. Therefore, the tradeoffs required in a run-time data base supporting a SAF system are very different from those for a manned simulator system.

Currently, simulation maps, which closely resemble the 1:50,000-scale source maps that may have been used to create a synthetic environment terrain data base, are produced for use by the crews of manned simulators. These special maps are needed because the synthetic

environment terrain data bases have only limited fidelity relative to the real world. If the fidelity of synthetic environment terrain data bases can be improved in the future, this will no longer be necessary. However, if the performance of image generators does not improve sufficiently to significantly reduce or eliminate the constraints that they currently place on feature density, it may be necessary to begin producing simulation DTD outputs, that, like simulation maps, match the synthetic environment terrain data base in order to support the C^3I systems carried by the vehicles.

The following sections briefly discuss the types of requirements associated with each of these areas. Posses of the DIS Simulated Environment Working Group, Land Subgroup, and Computer Generated Forces (CGF) Working Group, are currently working to define requirements in several of these areas, including infrared sensor modeling and mobility:

4.1 VISUAL/SENSOR

Visual and sensor simulation depend heavily on the material composition information contained in a synthetic environment terrain data base. Unfortunately, many different classifications of materials exist, at different levels of abstraction, and are designed for different purposes. Groupings of materials that make sense for visual sensors may not be appropriate for infrared or radar sensors. For example, the inclusion of Mud/Tidal Flats within the Desert/Sand surface material category in DFAD Level 2 is inappropriate, as wet and dry materials have very different thermal characteristics. The E^2DIS project has done some initial work on the development of a hierarchical set of material categories for use in synthetic environments, separating such high-level material categories as Water (including ice and snow), Soils, and Vegetation, as well as man-made materials.

For manned simulators, image generators and radar simulators produce synthetic imagery that is displayed to the crew, through Out-the-Window displays, night vision goggles, and display screens showing infrared or radar information. This synthetic imagery is generated using a polygonal representation of the synthetic environment.

For SAF systems, visual and sensor detection are modeled at a more abstract level, using line-of-sight and probabilistic detection models. The more sophisticated of these take the partial occlusion of entities into account, by intervening terrain, vegetation, cultural features, and even other vehicles in the area. The determination of the visibility of an entity to an observer and the determination of whether or not that entity is actually detected by the observer are not normally separated, but are combined in a single algorithm.

4.1.1 VISUAL

Visual models primarily dependent on the optical properties of various materials, include:

- Surface type (diffuse, directional, bidirectional) and roughness
- Diffuse reflection coefficient
- Spectral reflectance.

This information is typically derived from a set of surface material categories via table lookup. For simpler terrain features, such as areas of bare ground, road surfaces, or grassland, colors or generic textures are selected by the data base developers based on surface material attribute information, or simply on the nature of the feature itself. These colors or textures are then applied to all polygons that are derived from those features. More complex, man-made features, such as bridges and buildings, are seldom composed of a single, uniform material. The appearance of these features is primarily determined by the modeler who creates the 3-D models used to represent those features. Each polygon that makes up the model may have a material type associated with it. Frequently, texture patterns, either generic or specific, are applied to the individual polygons that make up a model to provide additional visual detail.

Each synthetic environment terrain DBGS includes libraries of generic or geotypical 3-D models and texture patterns. These libraries are used to support multiple data bases, so that only geospecific models need to be constructed as part of each data base generation effort. For example, the CCTT program defined a mapping between DFAD and ITD features and a collection of generic models and basis sets. This mapping is not necessarily one-to-one. The same basic industrial building model is used to represent a number of different types of DFAD cultural features related to various types of industries.

4.1.2 INFRARED/NIGHT VISION

Infrared sensor simulation depends on the thermal characteristics of various materials, including:

- Thickness
- Density
- Specific heat

- Conductance

- Absorptivity and emissivity.

Depending on the thickness of the surface material, this information may be needed for any underlying materials, as well as for the surface material. The same basic material composition information is typically used to create both visual and infrared representations, with different look-up tables being used to create different resulting "colors." Infrared sensor models are quite sensitive to dynamic and interactive effects in the environment, such as the position of the sun, the weather, shadows, etc. Polygonal representations of natural terrain features do not provide a sufficient level of detail to support the creation of realistic infrared imagery, so texture patterns are commonly used. The U.S. Army Night Vision Laboratory has performed some initial work in the development of infrared signatures for the ground surface and vegetation.

4.1.3 RADAR

Radar models primarily depend on three characteristics of terrain features: material composition, surface shape, and surface roughness. For airborne radars looking down on the terrain, DFAD provides a basic level of support in the form of a list of Surface Material Categories/Radar Significance Factors, a value associated with every feature, so that for any 2-D location, an SMC/RSF value can be determined. FACC defines a more comprehensive list of material composition categories, and several different material-related attributes, but unfortunately does not associate them with all features in a uniform manner. Ground-based radars, which are not currently supported by any of the terrain DBGS systems examined, may require more detailed, and fully 3-D material composition information.

The radar simulators that are supported by the MTSS and SOF ATS terrain DBGSs produce different types of radar displays, including terrain-following/terrain-avoidance (TF/TA) radar displays, that simply show the contours of the terrain at a specific altitude, and precision ground mapping radar displays that show detailed views of the ground surface.

4.2 MOBILITY

A mobility model determines the maximum movement speed of a particular vehicle type, given the characteristics of that vehicle type, the characteristics of the driver, and the characteristics of the terrain. The most well known mobility model is the NATO Reference Mobility Model—II (NRMM-II), that deals with on-road mobility, off-road mobility, and gap crossing, and is managed jointly by the U.S. Army Corps of Engineers Waterways Experiment

Station (WES) and U.S. Army Tank and Automotive Research and Development Command (TARDEC). The terrain-related mobility factors that NRMM-II takes into account include:

- Soil type
- Soil Moisture/Strength
- Slope
- Surface Roughness
- Vegetation Stem Size/Spacing
- Obstacle Geometry
- Obstacle Recognition Distance.

The key factor in standardizing the above parameters is achieving consensus on how their values should be measured, represented, quantized, and coded to achieve a common level of abstraction. For example, a simple mobility model may classify soils into only two types: fine and coarse, while a more detailed model may use 20 or 30 different soil types. Similarly, the calculation of slope at a given location, and in a particular direction, depends heavily on how the terrain surface is represented.

WES supplied the material codes used in the CCTT terrain data base for visualization, as well as the 30 terrain types used for vehicle performance, and is working with the Army Material Systems Analysis Activity (AMSAA) to develop mobility model standards at the vehicle and unit levels.

The CCTT manned modules use a mobility data base to limit the movement speed of the simulated vehicles.

SAF systems, such as ModSAF, incorporate mobility parameters into the terrain data base at the polygon level, and use a mobility model to limit the movement speed of the SAF vehicles over the terrain.

4.3 TERRAIN REASONING

As mentioned above, terrain reasoning occurs at two different levels, referred to here as direct and symbolic, using representations of the terrain at two different levels of abstraction. Direct terrain reasoning is concerned with the real-time decision-making that is performed by the crew of a vehicle as they perform their mission, and is based primarily on the crew's direct view

of the surrounding terrain. Symbolic terrain reasoning is concerned more with non-real-time planning activities, performed by a vehicle or unit commander, using information, such as a map, that describes terrain not currently within direct view.

In a manned simulator, direct terrain reasoning is performed in real-time by the live crew of the vehicle, using the information presented to them by the various visual and sensor displays available. Symbolic terrain reasoning is primarily performed before the simulation exercise begins, in preliminary planning and briefing sessions.

In a SAF vehicle or unit, direct terrain reasoning is performed using the same polygonal representation of the terrain that is used to create the visual and sensor displays. Terrain reasoning algorithms access this information, and perform calculations to determine obstacle and target detection, tactical maneuvering, etc. Symbolic terrain reasoning is performed using either the polygonal representation, or a higher level vector representation of the terrain, particularly for activities such as movement planning.

Both direct and symbolic terrain reasoning algorithms in a SAF system use combinations of spatial, thematic, and topological access to terrain information. Spatial access is used to locate terrain features and primitives which are nearby to the vehicle, or within the vehicle's field of view, while thematic access may be used to look for particular types of features, such as vegetation features, that can provide cover. Topological access is much more efficient for navigation and movement planning activities, and constructing or tracing paths through the terrain, either at the polygonal or vector level.

If a human operator can take over the direct operation of a particular SAF vehicle, then the operator will perform direct terrain reasoning using the perspective view display(s) that are provided to him. A human SAF operator also may perform symbolic terrain reasoning using a PVD showing the locations of moving entities on a map background derived from the synthetic environment terrain data base.

There are three conclusions that can be drawn concerning SAF terrain data requirements:

1. With respect to content, a SAF system should not require any terrain information that is not required for the operation of the corresponding manned simulators, or for the operation of the corresponding live vehicles. However, because of the real-time performance constraints of SAF systems, this information may be organized very differently than in these other systems.

2. The representation of terrain features and attributes may be more abstract in a SAF system than they are in the corresponding manned simulator in order to improve performance. Also, SAF terrain reasoning algorithms may not require the level of detail needed to support human crews (in either a simulator or a live vehicle).

3. Because a SAF system uses both the polygonal representation of the terrain for vehicle mobility, sensor simulation and direct terrain reasoning, and the vector representation of the terrain for symbolic terrain reasoning, it may require a higher degree of consistency between these two representations than other systems.

5. CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the conclusions reached as a result of this study, and the recommendations for further actions based on those conclusions.

5.1 CONCLUSIONS

The conclusions of this study can be grouped into three areas:

- Those having to do with synthetic environment terrain data base generation processes

- Those having to do with DTD problems and issues in synthetic environment terrain data base generation

- Those having to do with the organization of synthetic environment terrain data base requirements.

Each of these is summarized briefly below.

Synthetic Environment Terrain Data Base Generation Processes

The four synthetic environment terrain data base generation processes described in this report are basically similar. They all use standard DTD products, primarily DTED, DFAD, and ITD, supplemented with a variety of imagery, cartographic, and other miscellaneous sources. These are processed to create a representation of the terrain surface, a representation of the features that lie on the surface, a collection of 3-D models of features and feature components, either geospecific or geotypical, and a collection of texture patterns, again, either geospecific or geotypical. These are then integrated with one another to form a polygonal representation of the environment (in the SOF ATS terrain DBGS, this occurs in real-time within the ESIG-4000 image generator). This integrated, polygonal representation is then used to create run-time data bases for one or more image generators (which also support IR), radar simulators, SAF data bases, mobility data bases, and/or simulation maps.

Some of the characteristics of these synthetic environment terrain data base generation systems are summarized in Table 1. These systems group into two pairs, each addressing a different domain. The TEC DPC and CCTT terrain DBGSs are primarily concerned with ground vehicle simulation applications. They primarily use high-resolution DTD sources to create data bases that cover small (100 km by 100 km) areas. The creation of each data base requires approximately 6 months.

Table 1. Comparison of Synthetic Environment Terrain DBGSs

	TEC DPC Terrain DBGS	CCTT Terrain DBGS	MTSS Terrain DBGS	SOF ATS Terrain DBGS
Purpose	Army/Joint training exercises	Army training exercises	USAF SOF aircrew training & mission rehearsal	USAF SOF aircrew training & mission rehearsal
Database Extent	~100 by 100 km	~100 by 150 km	~50,000 to 200,000 NM^2	~500,000 NM^2
Time to Produce	~6 months	~6 months	5 days	48 hours
Standard DTD Sources	DTED 2 or 1; TTD, ITD, and/or DFAD 1	DTED 2; ITD and DFAD 1	DTED 1, 2 & 3; DFAD 1, 1C, 2 & 3C	DTED 1 & 2; DCW, DFAD 1, 1C, 2 & 3C, ITD
Principal Software Tools	DSPW, ARC/INFO, CMU TIN SW, S1000™, AutoCAD™	EaSIEST ARC/INFO, SOCET Set, Adobe Photoshop	TARGET, Trifid, LEOW, EaSIEST[2]	SOF ATS (ARC/INFO, AutoCAD™), EaSIEST
Visual/IR DB Products	SIMNET, Vistaworks™, MultiGen®	ESIG-3000	CompuScene V, PT-2000, SE-2000, MultiGen® ESIG-4000[2]	ESIG-4000[2]
Radar DB Products			MH-53J, MH-60G, C-130	MC-130H
Mobility DB Products		CCTT Mobility[1]		
Exchange DB Products	S1000™	SIF/SIF++	DTED, DFAD, SIF	SIF, DTED, DFAD[2]
CGF/SAF DB Products	SIMNET, CTDB	CCTT SAF[1]	CTDB	CTDB[2]
Plan View Display	(CTDB-based)	CCTT PVD[1]	(CTDB-based)	(CTDB-based)
Maps	Sim Maps (TLM-based)	Sim Maps (TLM-based)		

1 – Produced from SIF/SIF++ DB in separate processes
2 – Planned future capabilities

However, the MTSS and SOF ATS terrain DBGSs create very large data bases for special operations forces aircrew training and mission rehearsal, and produce these data bases quickly using primarily medium-resolution DTD sources. These are highly automated systems, with interactive processing limited to the correction of major problems in the source data, and to the creation of a few, small inset areas of high detail (i.e., target areas).

All of these systems use very different methods of representing the terrain surface. SOF ATS uses gridded DTED. CCTT uses a multi-level grid. TEC DPC and MTSS both use TINs, however with very different structures, and with TEC DPC's TINs incorporating some integrated transportation and drainage features. Each system is built employing a different software toolkit (S1000™, EaSIEST, TARGET, and SOF ATS), each of which converts the terrain surface and features into polygons in a different way. Also, each system is aimed at a different image generator, or group of image generators, that place different constraints on the data base generation process, and make interchange of products extremely difficult. All of the systems can produce SIF as an output for exchange with other systems, but only the MTSS and SOF ATS can accept SIF as an input source.

Synthetic Environment DTD Problems and Issues

NIMA digital topographic data products, such as DTED, DFAD, and ITD, are the primary inputs to the synthetic environment terrain data base generation process. However, there are several problems associated with the current NIMA DTD products relative to the needs of this process. In approximate order of importance, these problems are:

1. Lack of availability at the necessary levels of detail

2. Lack of consistency, including geometry, feature classifications, attribute values, and feature connectivity

3. Lack of correlation/integration between terrain elevation and feature data

4. Lack of correlation/integration between multiple thematic feature coverages

5. Lack of completeness, with respect to features, attributes, and relationships.

Surprisingly, perhaps, the level of detail of the existing standard DTD products is not currently a problem. This is because of the limitations of current generation real-time image generators, rather than the actual requirements of simulation applications.

The lack of current, complete high-resolution standard DTD products is the greatest problem that must be faced by synthetic environment terrain data base developers. Because of this, terrain data base generation systems must be capable of using a wide variety of alternative data sources, including various types of imagery and existing cartographic products. This greatly

complicates the front end of these systems. There is no simple short term solution to this problem, though products such as CIB and VMap Level 2 will help to some degree, as well as users defining requirements for the production of such data.

Terrain data base developers currently expend long amounts of time and significant effort correcting or eliminating consistency problems in the older DTD products, including poorly formed features, elevation anomalies, inconsistencies across cell or manuscript boundaries, and feature network connectivity problems. The thinning of transportation and drainage networks, while maintaining network integrity, is a difficult problem for synthetic environment terrain data base developers. The quality control improvements in NIMA's DPS are expected to eliminate most of these problems in new products, but terrain data base generation systems will still have to deal with the older products until they are completely replaced by new production.

Terrain data base developers also expend time and effort attempting to integrate terrain elevation and 2-D feature information to create a realistic 3-D representation. Because DTED and DFAD, or ITD, have been produced by different processes and/or from different sources, it is not surprising that they do not correlate very well. Features cannot simply be draped over the terrain surface to meet the requirements of ground vehicle simulation applications. Roads must have reasonable pitch and roll angles, rivers must run downhill, and lake surfaces must be flat. A significant amount of research and development has been, and is being, performed to develop techniques to integrate various types of 2-D features with the terrain surface. NIMA's DPS has the capability of producing terrain elevation and 3-D feature information in a correlated manner, with similar, if not identical, accuracy. A single integrated product, combining spot elevation posts with 3-D feature coordinates, collected at ground level from the same stereo imagery source, would support the efficient generation of high quality synthetic environment terrain data bases.

Feature data organized in multiple thematic layers cause problems for synthetic environment terrain data base generation systems, which ultimately require a single feature layer representing the appearance of the terrain. Correlation problems between features in separately produced thematic layers create additional editing work for terrain data base developers. Even when the DTD is initially correlated, independent thinning, generalization, or editing of features in different layers can easily create additional correlation problems, as the locations of features relative to one another are changed. While VPF is capable of supporting a single integrated feature coverage, all VPF-based products, to date, consist of multiple thematic coverages. A VPF-based product consisting of a single integrated coverage, or at least the smallest possible number of coverages, would greatly facilitate the generation of synthetic environment terrain data bases.

Finally, existing and forthcoming DTD products do not contain all of the geometric and attribute information required for synthetic environment terrain data base generation. Also, many ITD features and attributes are currently discarded by terrain data base developers, either

because they are not consistent, they are not adequate, or they are superfluous to the creation of 3-D representations of the environment. For synthetic environment terrain data base generation, each feature must include the geometric and attribute information necessary to support the reconstruction of the feature as a 3-D object. Specific problems arise at all locations where there is more than one significant elevation, such as bridges, overpasses, and tunnels. Also, while FACC contains several attributes that deal with the material composition of various types of features, there is no simple way to determine the material composition of all features in the newer VPF- and FACC-based products.

The above problems and issues provide several requirements for standard DTD products that are to be used for synthetic environment terrain data base generation:

1. Synthetic environment applications involving the simulation of ground vehicles require DTD coverage at "Level 2" resolution (i.e., 1:50,000-scale equivalent) wherever (in the world) the simulation is exercised

2. Synthetic environment applications require DTD that is consistent, seamless, and free of anomalies

3. All features which are part of a network (transportation, drainage, etc.) must include an attribute identifying the level of significance of that feature within the network, for the application at hand, such that all features with significance levels below a specified threshold can be removed without destroying the overall integrity of the network

4. Synthetic environment applications require 3-D digital terrain elevation and feature data that is produced from source material, with the same level of geopositional accuracy, attribute consistency and completeness, and is fully correlated

5. DTD products to be used for synthetic environment terrain data base generation must report all 3-D coordinate locations at the terrain surface, or must clearly indicate the relative height of each location above or below the terrain surface

6. Synthetic environment applications require DTD feature data in an integrated form, with topological consistency within and across layers, and with a high degree of relative accuracy between nearby features

7. DTD products that are to be used for synthetic environment terrain data base generation must contain sufficient geometric and attribute information to allow all features to be reconstructed as 3-D objects, and to be positioned correctly relative to all nearby features

8. DTD products to be used for synthetic environment terrain data base generation must be capable of reporting multiple significant elevations at the same location, such as at

bridges and overpasses, and must represent the true connectivity of the features that meet at (or pass through) such locations

9. DTD products to be used for synthetic environment terrain data base generation must provide surface material information for all features.

Several other issues are important to synthetic environment terrain data base generation. These include:

1. The differences between traditional cartographic forms of abstraction and the form of abstraction provided by synthetic environments

2. The detrimental impact of using cartographic data sources in the generation of synthetic environment terrain data bases

3. The importance of metadata in the synthetic environment terrain data base generation process

4. The variety of different terrain surface representations used by synthetic environment terrain data base developers

5. The impact of full topology in forthcoming VPF products on the synthetic environment terrain data base generation process

6. The use of commercial GIS tools in the synthetic environment terrain data base generation process

7. The impact of image generator constraints on the synthetic environment terrain data base generation process.

Scale in the traditional cartographic sense is meaningless for digital topographic data, however DTD products are still commonly described in terms of their "equivalent" scale. The feature extraction and product generation rules used in creating DTD products are still based, to a considerable extent, on the traditional concept of paper maps and scale. The concepts of spatial data abstraction used in traditional cartographic products, which are symbolic representations of the terrain, and the type of abstraction that is reflected by a synthetic environment which is used to generate full-scale, 3-D perspective views of the terrain, are clearly different, though related. Much of the information contained in current DTD products, such as the ITD slope polygons, cannot be used by synthetic environment terrain data base generation systems because it does not support the characteristics of the synthetic environment abstraction. These two different abstractions do share a common foundation based on the tactical significance of various types of features. The similarities and differences between these two concepts of spatial data abstraction need to be further investigated and understood in order to relate the requirements for synthetic

environment terrain data to the requirements for current DTD products. The concept of multiple levels of detail, for both polygonal and vector terrain representations, and the MEDS concept, are related to this issue.

The use of existing cartographic sources to generate DTD products more quickly, such as VMap, will help to address the data availability problem. However, the quality of the DTD produced in this way will be limited, and will not be well suited for the generation of synthetic environments, because cartographic abstraction generalizations and symbolization have been applied to the data when the source map was created.

Metadata is essential in order for users to understand the quality of a particular DTD product and the tradeoffs involved in its use. However, existing synthetic environment terrain data base generation systems do not always preserve the metadata associated with the original sources that they use, nor do they record the impacts of the processing that they perform on the quality of the resulting data base.

The variety of representations of the terrain surface that are used by current synthetic environment terrain data base generation systems, including regular grids, multilevel grids, and triangulated irregular networks, is a significant obstacle to the standardization of synthetic environment terrain data bases. Currently, these representations are strongly influenced by the polygon density constraints of real-time image generators. A baseline terrain surface representation that integrates all independent measurements of terrain surface coordinates is badly needed. The terrain elevation posts and 3-D feature points produced by NIMA's DPS could be combined to create such a baseline representation, which would form a basis of comparison for all other representations.

Existing synthetic environment terrain data base generation systems do not take topology into account, except for the Level 1 topology associated with transportation and drainage networks. The advent of VPF-based products with full topological information (Level 3) will have a large impact on these systems if they are to preserve this information, which is needed by SAF systems to support terrain reasoning. Those terrain data base generation systems which rely on commercial GIS systems should adapt more easily than those that use custom software to perform various types of feature manipulation. However, commercial GIS systems currently have limitations relative to their ability to process 3-D feature data and terrain elevation data in an integrated manner.

The memory and real-time performance limitations of specific image generators have an extremely strong influence on all aspects of the synthetic environment terrain data base generation process. In order to meet polygon budget constraints, features are discarded, thinned, and generalized, terrain elevation data is resampled, and both elevation posts and feature vertices are moved to better match the memory management architecture of the specific image generator with which the data base will be used. Image generator constraints currently take precedence over data base fidelity. If synthetic environment terrain data bases are to be standardized, their

dependence on specific image generator constraints must be limited to the greatest possible extent.

Synthetic Environment Terrain Data Base Requirements Framework

With respect to ground vehicle simulation applications, synthetic environment terrain data base requirements can be organized according to the types of terrain-related operations that these simulations perform. These include:

- Sensor Simulation, which dynamically models, either symbolically or through the creation of synthetic imagery, those elements of the terrain that can be detected by various types of sensors, including:

— Visual (Out-The-Window)

— Infrared/Night Vision

— Radar

- Movement Simulation, which dynamically models the movement of the simulated vehicle over the constructed surfaces

- Terrain Reasoning, which dynamically models the terrain-related decision-making performed by the crew, whether live or simulated, including two levels:

— Direct terrain reasoning, modeling the terrain-related reasoning of the crew concerning those elements of the terrain that can be directly viewed, using the output of the sensor simulators

— Symbolic terrain reasoning, modeling the terrain-related reasoning of the crew concerning those elements of the terrain that are not in direct view, using hardcopy maps or DTD.

These categories can be used as a framework for the organization of synthetic environment terrain data content requirements. Ideally, all platforms of a particular type in a networked simulation would behave in exactly the same manner, and would use exactly the same terrain data, regardless of whether the simulation is using a live vehicle, a manned simulator, or a SAF system. However, in practice, manned simulator systems are primarily concerned with the generation of realistic real-time OTW imagery, using a polygonal representation of the terrain. SAF systems are concerned with simulating relatively large numbers of vehicles in real time, including simulating, to at least some degree, the behavior of the crews of those vehicles. Therefore, the sensor and mobility models used by SAF systems tend to be much simpler. Both polygonal and vector representations of the terrain are used by SAF systems.

In manned simulators, visual and sensor models are used to create synthetic imagery to be viewed by the crew. In SAF systems, more abstract models are used that determine which other entities and objects in the environment are detected. Visual and sensor simulation depend primarily on the material composition information contained in a synthetic environment terrain data base. Material information at the feature level is propagated down to the individual polygons that make up the low-level terrain representation, including those in 3-D models. Texture patterns are used to provide the illusion of greater detail. Visual and radar models depend on the reflectivity characteristics of each surface element, while infrared models require information on the thermal characteristics. A comprehensive, hierarchical classification of materials is needed to support visual and sensor simulation at multiple levels of abstraction.

A mobility model determines the maximum movement speed of a simulated vehicle, based on the characteristics of the terrain, the vehicle, and the driver. The NATO Reference Mobility Model—II, is currently the de facto standard mobility model. It uses soil type, soil moisture/strength, slope, surface roughness, and vegetation and obstacle characteristics.

In manned simulators, terrain reasoning is performed by the live crew. Direct terrain reasoning is performed in real time, based on the information available to them, and comes primarily through the visual and sensor displays of the simulator. It includes such activities as steering the vehicle and scanning for targets. Symbolic terrain reasoning is mostly performed before the exercise, using maps and their electronic equivalents, primarily for planning purposes. In SAF systems, terrain reasoning algorithms, which are still in the very early stages of development, access the synthetic environment data base to simulate these activities. Direct terrain reasoning in a SAF system primarily uses the polygonal representation of the terrain, while symbolic terrain reasoning may use a vector representation to plan route over a road network and/or cross country.

5.2 RECOMMENDATIONS

Of the existing and planned NIMA DTD products, the DTOP component of the TTD product comes closest to meeting the general requirements of synthetic environment terrain data base generation. This is primarily because of its derivation from stereo imagery sources, its use of 3-D coordinates, and its extensive feature and attribute content. However, it does not fully integrate the terrain surface and features, and does not provide feature information in an integrated manner, but rather, is separated into a large number of thematic layers. Also, its feature and attribute content may actually be excessive for synthetic environment terrain data base generation in some respects, while remaining inadequate in others, since it does not necessarily provide all of the information needed to reconstruct 3-D representations of features.

Topics for Further Investigation

It appears that the TTD production process could be adapted relatively easily to produce an additional product, in conjunction with TTD, that would greatly aid the generation of synthetic

environment terrain data bases. However, several important issues need to be investigated further before this can be accomplished.

1. The restrictive impact of image generator constraints on the fidelity of synthetic environment terrain data bases should be investigated and quantified by comparing existing synthetic environment terrain data bases against the DTD sources used in their creation. Efforts to reduce or eliminate these impacts must be identified with associated timelines. This is complicated by the fact that synthetic environment terrain data bases use a variety of polygonal representations.

2. The similarities and differences between traditional cartographic abstraction, based on the concepts of map scale and symbolic communication, and the forms of abstraction necessary to support full scale, 3-D synthetic environment terrain data bases should be investigated further. This would identify which features and attributes are most important to the creation of synthetic environments. The descriptions of DFAD and ITD features and attributes used in this report, particularly in Appendix A, provide a starting point, however are not sufficient to answer this question.

3. The TTD production process should be examined to determine its degree of compatibility with synthetic environment terrain data base generation, including:

— Elevation post and 3-D feature extraction from stereo imagery

— Data extraction rules

— Quality control mechanisms

— DTOP product finishing rules.

4. The contents of the DTOP product, in terms of features and attributes, should be examined in detail to determine its compatibility with the needs of synthetic environment terrain data base generation, to identify both current content, which is not needed for synthetic environment terrain data bases, and missing content, which is needed to construct 3-D representations of all features. This examination should take the various MEDS levels into account, with the goal of identifying the lowest MEDS level which can meet synthetic environment terrain data base generation needs.

5. The DIGEST FACC should be examined relative to the content needed for synthetic environment terrain data base generation, as identified above, to determine the changes and additions needed, particularly with respect to the association between features and attributes.

Extensions to VPF for Synthetic Environments

Extensions to the VPF standard should be developed to address its limitations relative to synthetic environment terrain data base generation, including:

1. The integration of terrain elevation and 3-D feature information

2. Support for a standard baseline representation of the terrain surface and 3-D features.

Synthetic Environment Terrain Data

The development of DTD source data should be initiated to specifically support synthetic environment terrain data base generation based on user profiles. This new source should include the following characteristics:

1. Integrated 3-D feature and terrain elevation information, in either a single coverage or the smallest possible number of coverages, extracted from imagery sources

2. An optional baseline TIN, including all of the 3-D vertices measured from the imagery source

3. Features and attribute content based on the results of the above investigations of feature requirements for synthetic environments, TTD/MEDS, and FACC.

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6.1 TEC DPC TERRAIN DBGS

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APPENDIX A. DETAILS OF DTD USAGE

This appendix summarizes the use of digital topographic feature data in vector form, specifically DFAD and ITD, by the TEC DPC and CCTT terrain data base generation processes. Section A.1 summarizes DFAD and ITD feature usage by the TEC DPC terrain data base generation process. Section A.2 summarizes DFAD and ITD feature usage by the CCTT terrain data base generation process.

A.1 TEC DPC TERRAIN DBGS FEATURE DATA USAGE

Table A-1 summarizes the way in which DFAD features either have been, or could be, used by the TEC DPC terrain data base generation process, in conjunction with the S1000™ data base generation toolkit. For each feature, the S1000™ mechanism(s) for representing that feature is identified. In some cases, comments are added to further describe the usage of the feature. The 'Used' column indicates whether or not each DFAD feature has actually been used in constructing an S1000™ data base from DFAD sources, with blank entries for DFAD features which have not yet been encountered.

Tables A-2 through A-7 summarize how ITD features either have been, or could be, used by the TEC DPC terrain data base generation process, in conjunction with the S1000™ data base generation toolkit. The table format is identical to that of Table A-1. Each ITD thematic coverage is covered in a separate table.

Table A-1. TEC DPC DFAD Feature Usage

FACS Code	Description	S1000 Representation	Comments	Used?
1A010	Mine	Microterrain	No holes in terrain surface allowable; SIMNET cannot handle multiple z elevations	No
1A030	Quarry	Microterrain/Texture		No
1A031	Quarry Shear-Wall	Microterrain/Texture		No
1A040	Rig/Superstructure	3D Model		No
1B000	Disposal Site /Waste Pile	3D Model(s) and/or Microterrain	No Automated Placement; No Grouping (i.e. feature topology) in S1000	No
1B010	Wrecking Yard/ Scrap Yard	3D Model(s) and/or Microterrain	No Automated Placement; No Grouping (i.e. feature topology) in S1000	No
1C010	Blast Furnace	3D Model	Automated placement of point features only	No
1C020	Catalytic Cracker	3D Model	Automated placement of point features only	No
1C030	Settling Basin/ Sludge Pond	Microterrain/Texture		No
1D020	Solar Panel	3D Model	Automated placement of point features only	No
1D030	Substation/ Transformer Yard	3D Model	No Automated Placement; No Grouping (i.e. feature topology) in S1000; Automated placement of point features only	No
1F010	Chimney/ Smokestack	3D Model		No
1F020	Conveyor	3D Model	Automated placement of point features only	No
1F030	Cooling Tower	3D Model	Automated placement of point features only	No
1F040	Crane	3D Model	Automated placement of point features only	

Table A-1. TEC DPC DFAD Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
1F050	Dredge, Powershovel, Dragline	3D Model	Automated placement of point features only	
1F060	Engine Test Cell	3D Model	Automated placement of point features only	No
1F070	Flare Pipe	3D Model(s) and/or Microterrain	Automated placement of point features only	No
1F080	Hopper	3D Model	Automated placement of point features only	No
1I020	Mobile Home Park	3D Models	3D Models probably populated at less than 1 for 1 density	No
1J050	Windmill	3D Model		No
1K020	Amusement Park Attraction	3D Model(s) and/or Microterrain	See below	No
1K030	Amusement Park	3D Model(s) and/or Microterrain	3D Models probably populated at less than 1 for 1 density	No
1K080	Drive-in Theater Screen	3D Model	Automated placement of point features only	No
1K110	Grandstand	3D Model	Automated placement of point features only	No
1K150	Ski Jump	3D Model(s) and/or Microterrain		No
1K160	Stadium	3D Model(s) and/or Microterrain		Yes
1L015	Building	3D Models	3D Models probably populated at less than 1 for 1 density in urban areas; Automated placement of point features only	
1L050	Display Sign	3D Model	Automated placement of point features only	No

Table A-1. TEC DPC DFAD Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
1L070	Fence	3D Model or Treeline (Pole Set)	Possible automated placement, if nodes/segments are contiguous	Yes
1L110	Light Standard	3D Model		No
1L130	Monument	3D Model	Automated placement of point features only	No
1L160	Pipeline/Pipe	(1) S1000 Network File with Pipeline Attribute (2) 3D Model(s) or Microterrain	S1000 Overlay Tool Used as template to place models at regular intervals. Pipeline network file only used as input to SAF DB compiler	No
1L170	Plaza/City Square	3D Model(s) and/or Microterrain; Textures	No Automated Placement; No Grouping (i.e. feature topology) in S1000	No
1L220	Steeple	3D Model	Automated placement of point features only (Steeple normally part of Church model)	No
1L240	Tower (Non-Communication)	3D Model		Yes
1L260	Wall	3D Model or Microterrain		Yes
1M010	Depot (Storage)	3D Model(s); Textures	No Automated Placement; No Grouping (i.e. feature topology) in S1000	No
1M020	Grain Bin	3D Model	Automated placement of point features only	No
1M030	Grain Elevator	3D Model	Automated placement of point features only	No
1M040	Mineral Pile	3D Model(s) and/or Microterrain; Textures	No Grouping (i.e. feature topology) in S1000	No
1M050	Silo	3D Model	Automated placement of point features only	No

Table A-1. TEC DPC DFAD Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
1M060	Storage Bunker/ Storage Mound	3D Model(s) and/or Microterrain; Textures	Automated placement of point features only	No
1M070	Tank	3D Model	Automated placement of point features only	No
1M080	Water Tower	3D Model	Automated placement of point features only	Yes
1N010	Railroad Track	2D Polygonal Network; Polygon Type/Texture	Automated placement using S1000 Overlay Tool	No
1N050	Railroad Siding/Spur	(1) 2D Polygonal Network (2) 3D Model(s) and/or Microterrain (Platform or loading ramp)	Automated placement using S1000 Overlay Tool (Networks only)	No
1N080	Railroad Yard	(1) 2D Polygonal Network (2) Microterrain (Platform or loading ramp)	Automated placement using S1000 Overlay Tool (Networks only) Microterrain could be based on 3D Model converted into Microterrain surface	No
1P010	Cart Track	2D Polygonal Network; Polygon Type/Texture	Automated placement using S1000 Overlay Tool	No
1P020	Interchange	(1) 2D Polygonal Network/Intersection w/o Microterrain (2) 2D Polygonal Network/Intersection w/ Microterrain (3) ITIN "platform" w/2D Polygonal Network/Intersection	Manual Microterrain intersections are very time consuming	
1P030	Road	2D Polygonal Network; Polygon Type/Texture	Automated placement using S1000 Overlay Tool	

Table A-1. TEC DPC DFAD Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
1P050	Trail	2D Polygonal Network; Polygon Type/Texture	Automated placement using S1000 Overlay Tool	
1Q020	Aerial Cableway Pylon/Ski Lift Pylon	3D Model	Cables can be depicted using 2 point model placement	
1Q040	Bridge/Overpass/ Viaduct	3D Model and/or Microterrain	ModSAF recognizes bridges only as the intersection of road and river networks	
1Q040	Bridge Super-structure	3D Model Component	This is very difficult to do properly – involves complex multi-component models and multiple bounding volumes	No
1Q060	Control Tower	3D Model		No
1Q110	Mooring Mast	3D Model		No
1Q132	Tunnel Entrance/ Exit	Microterrain	Difficult multiple Z elevation problem	No
1Q140	Vehicle Storage/ Parking	3D Model(s) and/or Microterrain; Textures (for parking lot) treeline with texture pattern (for fence)	No Grouping (i.e. feature topology) in S1000	No
1R030	NAVAIDS	3D Model		No
1R035	Radar Reflector	3D Model		No
1T040	Power Transmission Pylon	3D Model		No
1T050	Communications Facility	3D Model(s)	Automated placement of single point features only	No
1T070	Telephone/ Telegraph Pylon	3D Model		No
1T080	Tower (Communication)	3D Model		No

Table A-1. TEC DPC DFAD Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
1U025	Aircraft Landing Pad	Microterrain and/or textures		No
1U050	Approach Lighting	Not economically representable	No "runway lights" in S1000	No
1U060	Apron/Hardstand	Microterrain and/or textures		No
1U130	Overrun/Stopway	2D Polygonal Network; Polygon Type/Texture	No network attribute definition for runways - use roads instead	No
1U150	Revetment	3D Model and/or Microterrain		No
1U160	Runway	2D Polygonal Network; Polygon Type/Texture	No network attribute definition for runways - use roads instead	No
1U160	Taxiway	2D Polygonal Network; Polygon Type/Texture	No network attribute definition for runways - use roads instead	No
2A040	Open Water (Except Inland)	3D Polygons – Textures and Polygon Types	Automated Application of Poly Type (5) and textures using Overlay Tool; Group Structure only recoverable running Defragment-ation in S1000 API	No
2B040	Breakwater	Microterrain		No
2B090	Drydock	3D Model and/or Microterrain		No
2B140	Jetty	3D Model and/or Microterrain		No
2B170	Offshore Loading Facility	3D Model and/or Microterrain	Automated placement of single point features only	No
2B190	Pier,Wharf	Normally Microterrain (possibly 3D Model)		No
2C010	Buoy	3D Model		No

Table A-1. TEC DPC DFAD Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
2D110	Platform	3D Model	Automated placement of single point features only	No
2D180	Wreck	3D Model	Underwater Object (?)	No
2H010	Aqueduct	(1) Microterrain (possibly converted 3D model) (2) Stream/River network along length of aqueduct)		No
2H020	Canal	(1) Stream/River network (2) Microterrain banks (3) Microterrain surface, if wider than 30 meters		Yes
2H030	Ditch	Microterrain banks		Yes
2H040	Filtration/Aeration Beds	Microterrain and/or textures	No direct definition in S1000	No
2H050	Fish Hatchery	Microterrain and/or textures	No direct definition in S1000	No
2H060	Flume	(1) Microterrain (possibly converted 3D model) (2) Stream/River network along length of flume)		No
2H080	Lake/Pond	Microterrain and/or textures	Minimum width normally 50 – 100 meters (greater than DFAD 2 spec = 30 meters)	No
2H110	Penstock	Microterrain and/or textures	No direct definition in S1000	No
2H130	Reservoir	Microterrain and/or textures	No direct definition in S1000	No

Table A-1. TEC DPC DFAD Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
2H140	River/Stream	(1) Stream/River network (2) Microterrain banks (3) Microterrain surface, if wider than 30 meters		Yes
2H150	Salt Evaporator	Microterrain and/or textures	No direct definition in S1000	No
2H180	Waterfall	Not Represented	Water polys obviously rise and fall with surface in S1000, but we generally don't have water "floating" above the land surface	No
2I020	Dam	Microterrain (possibly converted 3D model)		No
2I030	Lock	Microterrain (possibly converted 3D model)		No
2I050	Water Intake Tower	3D Model and/or Microterrain		No
2J030	Glacier	Microterrain and/or textures (Soil Representation not variable)	No direct definition in S1000	No
2J065	Ice Shelf	Textures and Polygon types (Soil Representation not variable)	No direct definition in S1000	No
2J070	Pack Ice	Textures and Polygon types (Soil Representation not variable)	No direct definition in S1000	No
2J080	Polar Ice	Textures and Polygon types (Soil Representation not variable)	No direct definition in S1000	No

Table A-1. TEC DPC DFAD Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
2J100	Snow Field/Ice Field	Textures and Polygon types (Soil Representation not variable)	No direct definition in S1000	No
2J110	Tundra	Textures and Polygon types	No direct definition in S1000	No
4A010	Ground Surface	Microterrain, Textures and Polygon types	No direct definition in S1000	No
4A015	Cleared Way	Depends on surrounding terrain	Undefined in S1000	
4A020	Salt Pan	Textures and Polygon types	No direct definition in S1000	No
4B010	Bluff/Cliff/Escarp-ment	Microterrain/Texture	May Be Defined By S1000 Surface Lines	No
4B070	Cut	Microterrain (Manual or Integrated TIN)	May Be Defined By S1000 Surface Lines	No
4B090	Embankment	Microterrain (Manual or Integrated TIN)	May Be Defined By S1000 Surface Lines	No
4B135	Island	Microterrain, Textures and Polygon types	May Be Defined By S1000 Surface Lines; Boundary also deriv-able from S1000 API Defragmentation	No
4B160	Rock Formation	(1) 3D Models/Microterrain (2) Surface Texture w/restrictive polygon type (i.e. SLOW GO or NO GO)	No Grouping (i.e. feature topology) in S1000	No
4B170	Sand Dunes	(1) 3D Models/Microterrain (2) Surface Texture w/restrictive polygon type (i.e. SLOW GO or NO GO)	No Grouping (i.e. feature topology) in S1000	No
5A010	Cropland (Cultivated)	Texture		No

Table A-1. TEC DPC DFAD Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
5A020	Hedgerow	Stamps or treelines	Treelines have no width and are generally penetrable (Assigning bounding volumes is impractical)	No
5A040	Orchard/Plantation	Stamps or treelines	Treelines have no width and are generally penetrable (Assigning bounding volumes is impractical)	No
5A050	Vineyard/Hops	Texture, Stamps, or treelines	Treelines have no width and are generally penetrable (Assigning bounding volumes is impractical)	No
5C010	Bamboo Cane	Stamps	Scene density is a real challenge – visual representation is not very credible	No
5C015	Firebreak	Depends on surrounding terrain	Undefined in S1000	No
5C030	Trees	Canopies (areas) Treelines (linear) Stamps (individual trees/points)	Canopies, stamps, and treelines are combined to give best visual representation within polygon budget	No
5D030	Swamp	Textures and Stamps		No
5D040	Marsh	Textures and Stamps		No
9B040	Diagnostic Point	Undefined		No
9D022	Homogeneous Aggregate Feature	Undefined		No

Table A-2. TEC DPC ITD Surface Configuration (Slope) Feature Usage

FACS Code	Description	S1000 Representation	Comments	Used?
2A040	Open Water (Except Inland)	3D Polygons – Textures and Polygon Types	In general, this feature information is derived from vegetation, hydrology, and surface materials, rather than the slope overlay	No
3A060	Slope	Implicit in Terrain/Surface Polygons	Not used as an input to S1000; Terrain Surface derived from digital elevation data, other sources; ModSAF postprocesses slope coverages from polygonal terrain	No
9D010	Miscellaneous	Undefined		No

Table A-3. TEC DPC ITD Vegetation Feature Usage

FACS Code	Description	S1000 Representation	Comments	Used?
1L020	Built-up Area	3D Models, surface textures, and polygon types	Surface texture used as tag for hardcopy maps	Yes
2A040	Open Water (Except Inland)	3D Polygons – Textures and Polygon Types	Automated Application of Poly Type (5) and textures using Overlay Tool; Group Structure only recoverable running Defragmentation in S1000 API	Yes
2H090	Wetlands	Textures and Stamps	Surface texture used as tag for hardcopy maps	Yes
4A010	Bare Ground	Microterrain, Textures and Polygon types	No direct definition in S1000; Poly Attribute Table can be used	Yes
5A010	Dry Crops (Cropland (Cultivated)	Texture		Yes
5A010	Wet Crops (Cropland (Cultivated)	Microterrain and/or textures	No direct definition in S1000; Rice Paddies done by building microterrain "dikes" either manually or via integrated TIN	Yes
5A010	Terraced Crops (Cropland (Cultivated)	Microterrain and/or textures	No direct definition in S1000; Rice Paddies done by manually building microterrain "dikes"	Yes
5A010	Shifting Cultivation	Texture	Terrain is not dynamic enough to "shift" textures	Yes
54010	Agriculture Area w/ scattered forests	Texture and Stamps		Yes
5A040	Orchard/Plantation (Deciduous/Coniferous/Mixed/Palm)	Stamps or treelines	Treelines have no width and are generally penetrable (Assigning bounding volumes is impractical)	Yes

Table A-3. TEC DPC ITD Vegetation Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
5A050	Vineyard/Hops	Texture, Stamps, or treelines	Treelines have no width and are generally penetrable (Assigning bounding volumes is impractical)	No
5B010	Grassland/pasture/ Meadow	Surface Texture/ Polygon Type		No
5B010	Grassland with scattered trees	Surface Texture/ Polygon Type; Stamps		No
5B010	Brushland/Scrub (Open to Medium)	Surface Texture/ Polygon Type; Stamps (possible treelines)		No
5B010	Brushland/Scrub (Medium to Dense)	Surface Texture/ Polygon Type; Stamps (possible treelines)		No
5C010	Bamboo/Wild Cane	Stamps	Scene density is a real challenge – visual representation is not very credible	No
5C030	Coniferous/Ever-green; Deciduous; Mixed Forest (Trees)	Canopies (areas) Treelines (linear) Stamps (individual trees/points)	Canopies, stamps, and treelines are combined to give best visual representation within polygon budget	Yes
5C030	Forest Clearing	Depends on surrounding terrain	Undefined in S1000	No
5D030	Marsh/Bog	Textures and Stamps		No
5D040	Swamp (Conifer-ous/Evergreen; Deciduous; Mixed; Mangrove)	Textures and Stamps		No
9D010	Miscellaneous Vegetation Feature	Undefined		No

Table A-4. TEC DPC ITD Surface Materials Feature Usage

FACS Code	Description	S1000 Representation	Comments	Used?
2A040	Open Water (Except Inland)	3D Polygons – Textures and Polygon Types	Automated Application of Poly Type (5) and textures using Overlay Tool; Group Structure only recoverable running Defragmentation in S1000 API	Yes
2J100	Permanent Snow Fields	Textures and Polygon types		No
4A010	Gravel, Well Graded	Textures and Polygon types		Yes
4A010	Gravel, Poorly Graded	Textures and Polygon types		Yes
4A010	Gravel, Silty	Textures and Polygon types		Yes
4A010	Gravel, Clayey	Textures and Polygon types		Yes
4A010	Sand, Well Graded	Textures and Polygon types		Yes
4A010	Sand, Poorly Graded	Textures and Polygon types		Yes
4A010	Sand, Silty	Textures and Polygon types		Yes
4A010	Sand, Clayey	Textures and Polygon types		Yes
4A010	Silt	Textures and Polygon types		Yes
4A010	Organic Silt	Textures and Polygon types		Yes
4A010	Inorganic Silt	Textures and Polygon types		Yes
4A010	Clays	Textures and Polygon types		Yes
4A010	Fat Clays	Textures and Polygon types		Yes
4A010	Organic Clays	Textures and Polygon types		Yes

Table A-4. TEC DPC ITD Surface Materials Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
4A010	Peat/Organic Soils	Textures and Polygon types		No
4A010	Evaporites	Textures and Polygon types (possible 3D models)		No
4B160	Rock Outcrop	(1) 3D Models/Microterrain (2) Surface Texture w/restrictive polygon type (i.e. SLOW GO or NO GO)	No Grouping (i.e. feature topology) in S1000	Yes
9D010	Miscellaneous	Undefined		No
9D020	Not Evaluated	Default to predominant or surrounding area attributes		No

Table A-5. TEC DPC ITD Surface Drainage Feature Usage

FACS Code	Description	S1000 Representation	Comments	Used?
2A030	Island	Microterrain, Textures and Polygon types	May Be Defined By S1000 Surface Lines;Boundary also derivable from S1000 API Defragmentation	No
2A040	Open Water (Except Inland)	3D Polygons – Textures and Polygon Types	Automated Application of Poly Type (5) and textures using Overlay Tool; Group Structure only recoverable running Defragmentation in S1000 API	Yes
2H010	Covered Drainage (Aqueduct)	(1) Microterrain (possibly converted 3D model) (2) Stream/River network along length of aqueduct	Possible Problem w/ multiple Z elevations	No
2H020	Canal/Channelized Stream/Irrigation Canal/Drainage Ditch, Narrow	(1) Stream/River network		No
2H020	Canal/Channelized Stream/Irrigation Canal/Drainage Ditch, Medium	(1) Stream/River network (2) Microterrain banks (3) Microterrain surface, if wider than 30 meters		No
2H020	Canal/Channelized Stream/Irrigation Canal/Drainage Ditch, Wide	(1) Stream/River network (2) Microterrain banks (3) Microterrain surface, if wider than 30 meters (time permitting)		No
2H055	Float Bridge/Raft Site	Microterrain approaches/texture concrete areas		No

Table A-5. TEC DPC ITD Surface Drainage Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
2H070	Off Route Ford	Passable Water Textures/Poly Types At Ford Site		Yes
2H140	Intermittent River/Stream, Narrow	(1) Stream/River network (crossing sites) (2) Microterrain banks (i.e. Integrated TIN)		Yes
2H140	Intermittent River/Stream, Medium	(1) Stream/River network (crossing sites) (2) Microterrain banks (i.e. Integrated TIN) (3) Microterrain/Surface texture as needed		Yes
2H140	Intermittent River/Stream, Wide	(1) Stream/River network (crossing sites) (2) Microterrain banks (i.e. Integrated TIN) (3) Microterrain/Surface texture as needed		Yes
2H140	Perennial River/Stream, Narrow	(1) Stream/River network (2) Microterrain banks (i.e. Integrated TIN)		Yes
2H140	Perennial River/Stream, Medium	(1) Stream/River network (2) Microterrain banks (i.e. Integrated TIN) (3) Microterrain/Surface texture as needed		Yes

Table A-5. TEC DPC ITD Surface Drainage Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
2H140	Perennial River/Stream, Wide	(1) Stream/River network (2) Microterrain banks (i.e. Integrated TIN) (3) Microterrain/Surface Texture		Yes
2H140	Stream Subject to Tidal Fluctuations (Narrow to Wide)	(1) Stream/River network (2) Microterrain/Surface texture as needed		No
2H140	Braided Streams (Narrow)	(1) Stream/River network		No
2H140	Braided Streams (Medium)	(1) Stream/River network (2) Microterrain/Surface texture as needed		No
2H140	Braided Streams (Wide)	(1) Stream/River network (2) Microterrain/Surface texture		No
2H140	Gorge (Narrow - Wide)	(1) Stream/River network (2) Microterrain banks (i.e. Integrated TIN) (3) Microterrain/Surface texture as needed		No
2I020	Dam	Microterrain (possibly converted 3D model)		No
2I030	Lock	Microterrain (possibly converted 3D model)		No
9D010	Miscellaneous	Undefined		No

Table A-6. TEC DPC ITD Transportation Feature Usage

FACS Code	Description	S1000 Representation	Comments	Used?
1N010	Single Track (Narrow, Normal, Broad Gauge) Railroad tracks	2D Polygonal Network; Polygon Type/Texture	Automated placement using S1000 Overlay Tool; Poly Width can replicate track gauge	Yes
1N010	Multiple Track (Narrow, Normal, Broad Gauge) Railroad Tracks	2D Polygonal Network; Polygon Type/Texture	Automated placement using S1000 Overlay Tool is inhibited by the parallel tracks (multiple track railroad represented by one line segment); Also placing multiple networks/tracks is very polygonally dense in S1000; Poly Width can replicate track gauge	Yes
1N010	Dismantled Railroad	2D Polygonal Network; Polygon Type/Texture	Could edit network segments to make disjoint before laying polygons in S1000 – not automated process	No
1N030	Passing Track, Narrow – Broad Gauge (Railroad Passing)	(1) 2D Polygonal Network	Automated placement using S1000 Overlay Tool (Networks only)	No
1N050	Siding Track (Narrow – Broad Gauge)	(1) 2D Polygonal Network (2) 3D Model(s) and/or Microterrain (Platform or loading ramp)	Automated placement using S1000 Overlay Tool (Networks only)	No
1N080	Railroad Yard (Narrow – Broad Gauge)	(1) 2D Polygonal Network (2) Microterrain (Platform or loading ramp)	Automated placement using S1000 Overlay Tool (Networks only) Microterrain could be based on 3D Model converted into Microterrain surface	No
1P010	Cart Track	2D Polygonal Network; Polygon Type/Texture	Automated placement using S1000 Overlay Tool	Yes

Table A-6. TEC DPC ITD Transportation Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
1P030	All Weather Hard Surface Highway	(1) 2D Polygonal Network; Polygon Type/Texture (2) Cut/Fill TIN/ITIN where appropriate	Automated placement using S1000 Overlay Tool	Yes
1P030	All Weather Loose Surface Highway	(1) 2D Polygonal Network; Polygon Type/Texture (2) Cut/Fill TIN/ITIN where appropriate	Automated placement using S1000 Overlay Tool	Yes
1P030	Fair Weather Loose Surface Highway	(1) 2D Polygonal Network; Polygon Type/Texture (2) Cut/Fill TIN/ITIN where appropriate	Automated placement using S1000 Overlay Tool	Yes
1Q040	Road Bridge	3D Model and/or Microterrain	ModSAF recognizes bridges only as the intersection of road and river networks	No
1Q040	Railroad Bridge	3D Model and/or Microterrain	ModSAF recognizes bridges only as the intersection of road and river networks	No
1Q040	Bridge Span	3D Model and/or Microterrain	ModSAF recognizes bridges only as the intersection of road and river networks	No
1Q058	Constriction	3D Model	Difficult to model in SIMNET due to multiple Zs	No
1Q068	Drop Gate Road	3D Model	Probably not dynamic model (Gate does not drop)	No
1Q068	Drop Gate Railroad	3D Model	Probably not dynamic model (Gate does not drop)	No
1Q070	Road Ferry	Microterrain approaches/texture concrete areas		No

Table A-6. TEC DPC ITD Transportation Feature Usage (Continued)

FACS Code	Description	S1000 Representation	Comments	Used?
1Q070	Railroad Ferry	Microterrain approa-ches/texture concrete areas		No
1Q118	Road Radius of Curvature	Undefined in S1000	Maybe useful in MultiGen®	No
1Q130	Tunnel Road (Entrance/Exit)	Microterrain/Road network through tunnel	Difficult multiple Z elevation problem	No
1Q130	Tunnel Railroad (Entrance/Exit)	Microterrain/Railroad network through tunnel)	Difficult multiple Z elevation problem	No
1U160	Airfield – Hard/ Paved Runway	2D Polygonal Network; Polygon Type/Texture	No network attribute definition for runways – use roads instead	Yes
1U160	Airfield-Loose/Unpaved Runway	2D Polygonal Network; Polygon Type/Texture	No network attribute definition for runways – use roads/trails instead	Yes
1U160	Landing Area (Hard/Paved)	2D Polygonal Network; Surface Polygon Type/Texture (Possible Microterrain)	No network attribute definition for runways – use roads instead	Yes
1U160	Landing Area (Hard/Paved)	2D Polygonal Network; Surface Polygon Type/ Texture (Possible Microterrain)	No network attribute definition for runways – use roads instead	Yes
2H070	On Route Ford	2D Network Priority – road under fordable stream polygons		No
9D010	Miscellaneous	Undefined		No

Table A-7. TEC DPC ITD Obstacle Feature Usage

FACS Code	Description	S1000 Representation	Comments	Used?
1L060	Dragon Teeth	3D Model	No Automated Model Placement	No
1L160	Pipeline	(1) S1000 Network File with Pipeline Attribute (2) 3D Model(s) or Microterrain	S1000 Overlay Tool Used as template to place models at regular intervals. Pipeline network file only used as input to SAF DB compiler (2D ModSAF display)	Yes
1L260	Wall	3D Model or Microterrain		No
2B070	Volcanic Dike	Micoterrain/Textures		No
2B220	Crossing Point (Ramp)	Microterrain approa-ches/texture concrete areas		No
2H100	Moat	(1) Stream/River net-work (2) Microterrain banks (i.e. Integrated TIN)		No
4B010	Escarpment (Bluff/Cliff)	Microterrain/Texture	May Be Defined By S1000 Surface Lines	No
4B070	Road/RR Cut	Microterrain (Manual or Integrated TIN)	May Be Defined By S1000 Surface Lines	No
4B080	Depression	Microterrain (Manual or Integrated TIN)	May Be Defined By S1000 Surface Lines	No
4B090	Embankment	Microterrain (Manual or Integrated TIN)	May Be Defined By S1000 Surface Lines	No
4B120	Road/RR Fill	Microterrain (Manual or Integrated TIN)	May Be Defined By S1000 Surface Lines	No
5A020	Hedgerow	Stamps or treelines	Treelines have no width and are generally penetrable (Assigning bounding volumes is impractical)	No
9D010	Miscellaneous	Undefined		No

APPENDIX A-2. CCTT TERRAIN DBGS FEATURE DATA USAGE

DFAD cultural point features were used as a secondary source for the CCTT "Desert" Data Base, to supplement the lack of cultural features in the primary ITD source. These DFAD point features were mapped to individual 3-D models, or, in some cases, clusters of 3-D models. This mapping is shown in Table A-8. A few features, such as advertising billboards, were not used, because: 1) they were of little tactical significance; 2) there was no model existing for such a feature; and 3) the number of instances of the feature in the data base was very low.

The use of ITD features in the CCTT "Desert" Data Base is summarized in Table A-9. For each ITD feature appearing in the "Desert" Data Base coverage area, the table identifies the type of the feature (P - Point, L - Line, A - Area), the thematic coverage layer(s) in which the feature appears (D - Surface Drainage, M - Surface Materials/Soils, O - Obstacles, S - Surface Configuration/Slope, T - Transportation, V - Vegetation), the number of occurrences of the feature within the data base coverage area, the description of the feature, and the strategy for implementing the feature, if it was to be implemented. Several features are deleted for various reasons. Features that did not occur in the ITD cells used to construct the data base do not appear in the table.

Table A-8. Mapping of DFAD Point Features to Models for CCTT "Desert" Data Base

FID Code	DFAD Feature Description	Number Instances	Mapped Model Description
101	Industry – Extraction (General)	7	2 Industrial Buildings, Pitched Roof
110	Industry – Processing (General)	1	4 Industrial Buildings, Flat Roof
113	Sewage Treatment Plant	1	Sewage Treatment Plant
120	Refinery	1	4 Industrial Buildings, Flat Roof
130	Industry – Power Generation (General)	1	Power Plant
136	Power Plant, Thermal	1	Power Plant
138	Substation	3	Transformer Yard
145	Solar Energy Electrical Collection Panels	1	No Model – Deleted
163	Light Fabrication Industry with Gable Roof (Pitched)	3	2 Industrial Buildings, Pitched Roof
181	Building (Industry)	1	4 Industrial Buildings, Flat Roof
182	Smokestack/Chimney	3	Buildings with Smokestacks
183	Conveyor	7	No Model – Deleted
186	Crane, Rotating	2	No Model – Deleted
189	Hopper	1	No Model – Deleted
222	Railroad Station	1	2 Industrial Buildings, Pitched Roof
260	Transportation – Bridges (General)	3	Auto Placement – Deleted
264	Bridge, Truss	3	Auto Placement – Deleted
267	Bridge/Deck	9	Auto Placement – Deleted
302	Commercial Buildings with Flat Roof	35	4 Industrial Buildings, Flat Roof
303	Commercial Buildings Circular with Flat Roof	1	4 Industrial Buildings, Flat Roof
304	Commercial Buildings with Gable Roof	38	2 Industrial Buildings, Pitched Roof

Table A-8. Mapping of DFAD Point Features to Models for CCTT "Desert" Data Base (Continued)

FID Code	DFAD Feature Description	Number Instances	Mapped Model Description
320	Public – Recreational (General)	2	School
341	Advertising Billboards	3	No Model – Deleted
352	Drive-in Theater Screen	1	No Model – Deleted
401	Dwellings, Multi-Family (General)	5	6 Apartments
402	Apartments/Hotels with Flat Roof	9	6 Apartments
420	Dwellings, Single Family (General)	161	6 Houses
421	Mobile Home	11	6 Houses
430	Agricultural – Buildings (General)	148	Farm Cluster Models
511	Radio/Television Tower, Type "A"	1	Radio/TV Tower
512	Radio/Television Tower, Type "I"	1	Radio/TV Tower
520	Microwave Tower, Type "A"	1	Microwave Tower
521	Microwave Tower, Type "I"	4	Microwave Tower
530	Miscellaneous Towers (General)	10a	Microwave Tower, Radio/TV Tower
541	Powerline Pylons, Type "A"	59	Power Pylon
542	Powerline Pylons, Type "H"	337	Power Pylon
544	Powerline Pylons, Type "Y"	2791	Power Pylon
561	Communications – Buildings (General)	11	Government Building
601	Government – Buildings (General)	2	Government Building
621	School with Flat Roof	3	School
650	Public – Religious (General)	5	3 Churches
681	Steeple	2	3 Churches

Table A-8. Mapping of DFAD Point Features to Models for CCTT "Desert" Data Base (Continued)

FID Code	DFAD Feature Description	Number Instances	Mapped Model Description
703	Airport Terminal/Base Operations	2	Control Tower
704	Hangar with Flat Roof	1	Hangar, Flat Roof
705	Hangar with Curved Roof	1	Hangar, Curved Roof
718	Radar Antenna, Tower Mounted	6	Radar Building with Radome
765	Lighthouse	1	No Model – Deleted
772	Barracks, Flat Roof	6	Military Barracks
774	Motor Pools	1	No Model – Deleted
776	Garage, Flat Roof	1	4 Industrial Buildings, Flat Roof
778	Depot	10	2 Industrial Buildings, Pitched Roof
790	Military – General Structures (General)	6	Military Barracks
791	Administration Building (Military)	6	Government Building
802	Tanks, Cylindrical, Flat Top	6	Storage Tank
804	Tanks, Cylindrical, Peaked/Conical Top	1	Storage Tank
805	Tanks, Cylindrical, Peaked/Conical Top, Tower Mounted	3	Water Tower
822	Grain Elevator	1	Silo
861	Warehouses	1	4 Industrial Buildings, Flat Roof
915	Islands	1	No Model – Deleted

Table A-9 ITD Feature Usage for CCTT "Desert" Data Base

FACS Code	Type	Layer	Count	Description	Implementation Strategy
1L020	A	V	29	Built-up Area	Delete; Too small
1N080	A	T	1	Railroad Yard	Delete; Join RR linear features
2A030	A	D	60	Island	Delete
2A040	A	S,V,M, D	272	Open Water	Retain in drainage layer; Delete others
2H020	A	D	3	Canal/Ditch	Delete; Use linear features
2H090	A	V	20	Wetlands	Snap-to-grid; Represent as marsh
2H140	A	D	1767	River/Stream, Gorge	Integrate with river networks and generalize
3A060	A	S	17531	Slope	Delete entire layer
4A010	A	V,M	4267	Bare Ground, Gravel, Sand, Silt, Clay, Peat/Organic Soil, Evaporites	Use vegetation layer for visual; Use material layer for mobility and to supplement visual
4B080	A	O	21	Depression	Delete; Represent with terrain skin
4B160	A	M	1840	Rock Outcrop	Unknown
5A010	A	V	53	Cropland	Map to farm
5A040	A	V	10	Orchard/Plantation	Map to orchard
5B010	A	V	18	Grassland, Pasture, Meadow	Map to farm
5B020	A	V	145	Brushland/Scrub/ Shrub	Map to desert brush
5C030	A	V	104	Forest (trees)	Some forest, some joshua
9D010	A	D,O	142	Misc. Feature	
		D	127	Intermittent Water Body	Map to dry lake & snap-to-grid
		O	15	Impact Area	Delete
1L260	L	O	36	Wall/Fence	Delete
1N010	L	T	333	Railroad Tracks	Create networks, generalize & map to single track

Table A-9 ITD Feature Usage for CCTT "Desert" Data Base (Continued)

FACS Code	Type	Layer	Count	Description	Implementation Strategy
1N030	L	T	1	Railroad Passing Track	Delete spurs
1N050	L	T	11	Railroad Siding Track	Delete spurs
1P010	L	T	1208	Cart Track	Create networks & generalize
1P030	L	T	14663	Road	Use attributes for 4-lane/2-land/dirt; Create networks & generalize
1Q040	L	T	6	Bridge	Delete; Fabricate new data
1U160	L	T	30	Runway	Use attributes for paved/dirt
2H020	L	D	117	Canal/Ditch	Map to rivers
2H100	L	O	3	Moat	Ft. Irwin flood control ditches
2H140	L	D	13492	River/Stream, Gorge	Thin to create networks & generalize
4B010	L	O	158	Escarpment (Bluff/Cliff)	Delete; Represent with terrain skin
4B070	L	O	105	Cut (Road/RR)	Delete; Represent with cut & fill
4B090	L	O	76	Embankment	Delete; Represent with cut & fill
4B120	L	O	240	Fill (Road/RR)	Delete; Represent with cut & file
9D010	L	D,O	31	Misc. Features	
		D	4	Aqueduct	Delete
		O	1	Conveyor Belt	Delete
		O	26	Shelterbelt/Wind-break	Delete
1Q040	P	T	305	Bridge	Delete; Fabricate new data
1Q045	P	T	168	Bridge Span	Delete; Fabricate new data
1Q118	P	T	43	Road Radius of Curvature	Delete
2H070	P	T	4	Ford	Delete